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# AERIAL SURVEILLANCE SPILL PREVENTION SYSTEM

C. L. Rudder, et al

McDonnell Aircraft Company

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# Aerial Surveillance Spill Prevention System

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An aerial surveillance system, consisting of four Hasselblad cameras and a Zeiss RMK 1523 camera, was evaluated for the remote detection of both real and potential spills threatening inland waterways. Twenty-three multiband and baseline missions were flown over oil refineries and other industrial sites located adjacent to the Mississippi River. Baseline flights were effective in counting storage tanks, locating and identifying storage equipment and pipeline systems and determining dike conditions. Stereoscopic analysis of baseline imagery was used to estimate the height of tanks and dikes, drainage patterns and the area of openly stored waste products. The multiband imagery was obtained by combining each of nine filters with each of three different black and white films. Spectral contrast image enhancement was accomplished by either suppressing or transmitting the target reflected radiation through proper film/filter selections. Spills, effluents and waste areas were hence identified on the multiband imagery. Normal and false color imagery was evaluated with the multiband imagery to determine the best film/filter combinations for the areas of interest. Finally the personnel, equipment and procedures required to implement an aerial surveillance spill prevention system were determined. (EPA)

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# AERIAL SURVEILLANCE SPILL PREVENTION SYSTEM

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# ABSTRACT

An aerial surveillance system, consisting of four Hasselblad cameras and a Zeiss RMK 1523 camera, was evaluated for the remote detection of both real and potential spills threatening inland waterways. Twenty-three multiband and baseline missions were flown over oil refineries and other industrial sites located adjacent to the Mississippi River. Baseline flights were effective in counting storage tanks, locating and identifying storage equipment and pipeline systems and determining dike conditions. Stereoscopic analysis of baseline imagery was used to estimate the height of tanks and dikes, drainage patterns and the area of openly stored waste products. The multiband imagery was obtained by combining each of nine filters with each of three different black-and-white films. Spectral contrast image enhancement was accomplished by either suppressing or transmitting the target reflected radiation through proper film/filter selections. Spills, effluents and waste areas were hence identified on the multiband imagery. Normal and false color imagery was evaluated with the multiband imagery to determine the best film/filter combinations for the areas of interest. Finally, the personnel, equipment and procedures required to implement an aerial surveillance spill prevention system were determined.

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# SECTION I

# CONCLUSIONS

The feasibility of an aerial surveillance spill prevention system for identifying and locating actual or threatened discharges of oil and hazardous polluting substances from onshore facilities into or upon inland waterways has been demonstrated. In addition, the personnel, equipment and procedures required to implement an aerial spill prevention system have been determined.

Baseline photographs, at a scale of approximately 1:4000, are useful for identifying potential spill threats to inland waterways from storage equipment, storage and processing tanks, pipeline systems, dike conditions and the presence of trash or debris in diked areas. Stereoscopic analysis of this imagery also permits estimating dike heights, drainage patterns and the runoff patterns from openly stored raw materials, all of which are aids in identifying potential spill threats.

Positive identification of spills as oil or hazardous materials is necessary to the determination of the potential threat. Multiband photographs are effective in providing spectral contrast enhancement for the identification of oil and oil waste in oil refinery areas. Multiband imagery at scales of 1:9000 or larger was found effective for detecting spills, effluents, and waste areas.

For aerial multiband photography, the preferred Kodak film/filter combinations for the detection of oil, oil derivatives and oil waste products are 2403/32, 2403/99, 2424/32 and 2424/99. Combinations 2424/99 and 2424/32 are recommended for detecting oil and oil derivatives spilled on soil. When the background is water, 2409/99 and 2403/32 are recommended. With both film types, filter 99 provides maximum image contrast of oil while filter 32 best distinguishes oil drainage patterns. Of the color films investigated, Kodak type 2448 permits the most effective detection of spills, effluents, and raw materials at industrial sites. The color photographs provide cues for the identification of many hazardous materials.

From available thermal infrared (8,000 to 14,000 nm) imagery of the same sites, it was determined that processing facilities, materials, and effluents which are "warm" can be readily detected. Such information provides useful indicators of activity. However, this additional information is not considered to be essential.

Aerial surveillance for the detection, identification, and location of actual and threatened discharges of oil and hazardous materials into waterways can be accomplished at reasonable cost with a photographic system. The system should be capable of producing both color and multiband photographs. When properly analyzed, such photographs will provide sufficient information for the assessment of real and potential threats.

# SECTION II

# RECOMMENDATIONS

The following recommendations are made for the implementation of an aerial surveillance spill prevention system for monitoring real and potential threats to inland waterways.

## Aircraft

The selected aircraft should have good flying qualities at altitudes of 1500 ft and above at air speeds above 100 knots. Its power plant should be adequate to maintain ground speeds of 120 knots during photographic operations. Interior space should be adequate for a crew of three and for installation and efficient access to the photographic subsystem described below.

## Photographic Subsystem

For multiband photography an array of four 70-mm cameras, with film magazines to accommodate at least 15 ft of film, is recommended. Motorized film advance and electrical operation of camera shutters is essential. Shutters should permit exposure of 1/250 to 1/500 second to reduce image smear to an acceptable level for ground speeds of 110-120 knots. The cameras in the array should be mounted with optical axes vertical. The quad-array should be attached to a mounting plate which is compatible with the aircraft camera mount. The combination provides adjustment for drift angle and leveling in two axes. The focal length of the camera should provide a minimum image scale of 1:9000 at operating altitudes. A baseline camera with 9-in. by 9-in. format, is recommended for baseline and stereographic photography. For best results, the mapping camera axis must be vertical in flight. The focal length of the camera should provide an image scale of 1:4000 at the operating altitudes. A view finder is recommended for determining start and stop times for the cameras. The camera control should include an intervalometer to provide properly spaced commands to insure correct overlap in successive frames.

Sixty percent overlap should be maintained in stereophotography. A command unit is required to initiate simultaneous exposures on the multiband camera array. Filters, filter holders, film cassettes, and other loose parts complete the photographic subsystem.

## Flight Crew

A crew of three, pilot, aerial photographer, and camera monitor, is recommended. The photographer's primary tasks are to select the initial and final camera exposures, monitor overlap and maintain camera level and crab. The camera monitor's tasks are to watch for possible camera malfunctions, and to monitor air traffic in the operating areas.

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## Film Processing

Precision film processing is required for both the multiband and baseline photography. The Versamat continuous roll film processor or equivalent is recommended over reel and tank developing. The Versamat represents a higher initial cost, but is more efficient for long term usage, provides quick image processing and requires minimum additional dark room accessories. If the aerial film is processed at the user's facility, a photoprocessing technician will be required to operate and maintain the photoprocessing equipment. Many aerial photographers are also capable of performing these duties.

## Image Analysis

For an image interpretation station, a standard light table capable of handling a 9-in. film format, a stereoscopic viewer, 10X and 30X magnifiers and a parallax bar are the minimum recommended equipment. The number of image interpretation stations and the total personnel requirement will be determined by the volume of imagery to be analyzed, the scale and quality of the aerial photographs, the requirement for detailed stereographic analysis, and the complexity of required reporting.

## Ground Truth

As an adjunct to the aerial surveillance system, a capability for determining ground truth is recommended. Visits to sites under aerial surveillance for ground level observation of spill threats, examination of protective measures, and collection of samples of suspect pollutants for on-site or later analysis can provide validation of the results of photographic analysis. Flight crew personnel and photointerpreters should be given the opportunity to participate in ground truth operations.

## Film and Filters

Kodak Film types 2405 and 2448 are recommended for taking black-and-white or color 9-in. format baseline photography, respectively. Similarly, Kodak Film type 2403 is recommended for taking the multiband photography and film type 2448 is recommended for taking color photography when required in the Hasselblad camera array. Kodak filters 99 and 32 are the minimum filters recommended to obtain the multiband photographs over oil refinery areas. Color, rather than multiband photography is presently recommended for monitoring industries using or manufacturing hazardous materials. Because the 70-mm cassettes are not light tight, camera magazine loading should be done in a dark room facility.

## Infrared Thermal Imagery

An infrared thermal imaging system is not recommended as part of the aerial surveillance spill prevention systems as sufficient information for adequate monitoring can be obtained from a multiband and baseline photographic system.

## Weather Conditions

The multiband and baseline photographs should be taken on clear days if possible. On hazy days, adequate multiband and baseline images can be recorded if the appropriate adjustment of exposure is made. Additional information on the effects of adverse weather conditions on multiband imagery is needed to extend the effectiveness of an aerial surveillance spill prevention system.

# SECTION III

## INTRODUCTION

The purpose of the project was to demonstrate the feasibility of an aerial surveillance system for the detection and location of real and potential spill threats to the inland waterways. It was initially postulated that conventional and multiband aerial photographs would provide sufficient data to accomplish this task. Results, reported herein, demonstrated that an aerial surveillance system can provide timely information at reasonable cost, for the detection, identification and threat assessment of real and potential spills of oil, oil derivatives and waste and other hazardous materials. In addition, preferred film/filter combinations were identified for the detection and identification of spilled materials using multiband photography.

The St. Louis area has a variety of industrial complexes that are located near or adjacent to the Mississippi River. A survey was made of imagery in the McDonnell Reconnaissance Laboratory Data Base and site selection was made with the guidance of the Environmental Protection Agency. These industries include two oil refineries, two barge loading facilities, a titanium plant, a chemical plant, a cement manufacturing plant, a sewage disposal plant, a steel mill and a thermo-electric plant. Site selection was based on proximity to the Mississippi River and the presence of industrial effluents and potential spill threats. Some of the industries are located behind a levee or flood wall which prevents direct surface drainage from these sites to the river. These non-adjacent river locations were investigated for two reasons. First, these sites discharge waste materials through public sewers or private drainage systems and therefore covertly threaten the inland waterway. Second, the analysis applied to these areas demonstrates the system capabilities that can be applied to other industries located adjacent to inland waterways.

Location and identification of real and potential spill threats requires determination of drainage patterns, dike heights, tank size, and the volume of detention ponds and waste areas. Such dimensional data can be derived from aerial photographs obtained with cameras capable of providing high geometrical fidelity and stereoscopic coverage. Consequently, the aerial surveillance system included a high quality mapping camera. Baseline flights used the mapping camera to record, in color and in black-and-white, imagery of the selected sites for detailed analysis.

Multiband photography combines various spectral filters with films having different spectral responses and provides contrast image enhancement of materials having particular reflective characteristics. By a judicious choice of film and filters, material identification can be made through the use of multiband photography. Positive identification of spilled material as oil or hazardous material is necessary to the meaningful assessment of a real or potential threat to inland or coastal waterways.

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The aerial system employed an array of four identical cameras for simultaneous recording of site images. Each camera was equipped with a different film/filter combination to produce the multiband photographs.

Ground truth is the term applied to a body of collected data gathered at the industrial sites of interest to aid and confirm the analysis of aerial imagery. On their initial plant visit, ground truth teams used mosaics constructed from baseline photographs to examine potential threat areas that included processing, storage and transportation facilities. Each area was labeled on the mosaic and pertinent data on waste treatment and removal techniques was kept in an appropriately labeled log book. Similarly, ground truth photographs of each area were taken, where possible, with a 35-mm hand held Nikon camera using Etachrome X film and appropriately labeled. From the initial ground truth information, the multiband flight areas were selected. The ground truth photographs and descriptions of specific areas were used to estimate the spectral signatures of the area of interest. Ground truth data relevant to aerial photography was also taken simultaneously with one multiband flight at each industrial site.

Advance arrangements were made with each company visited to allow the entry of ground truth teams. Initially, each company was notified by phone of the ensuing project and meetings were arranged to explain the program in depth. At these meetings, the evaluation of the aerial surveillance system rather than the monitoring of individual companies, was emphasized as the objective of this project. In general, sincere interest was expressed in the potential use of an aerial surveillance spill prevention system and a high degree of cooperation was obtained. Permission to take ground truth photographs was granted by most companies except for areas where government or company regulations prohibited photography. For this cooperation, each company was given a chance to review the draft report and was promised a copy of the final report. From knowledgeable representatives at each site, the ground truth team gained valuable understanding of plant functions, procedures and resources not readily apparent in the aerial photographs.

As with any photographic system dependent upon natural lighting, successful application requires adequate sunlight and a reasonably transparent atmosphere. No flights were attempted on overcast days, but useful results were obtained through light haze. Although the effects of air turbulence were not specifically evaluated, it was observed that gusty air can degrade both photographic image quality and air crew performance.

The following sections of this report describe in detail the aerial system used and the findings of the experimental program.

# SECTION IV

## DESIGN AND METHODS

### Camera System

The baseline photographic system requires a conventional mapping camera capable of producing images of high geometrical fidelity. This type of camera employs a six inch focal length lens and supplies a nine inch square film format. The camera system must fit an aircraft mount that provides leveling in two axes and drift compensation. A variety of cameras satisfy these requirements: the Zeiss RMK 1523 and RMK-A-15/23, the Fairchild CA-8 and T-11, the Wild Heerbrugg RC-8 and the Carl Zeiss Jena 11.5/188. Since it was readily available, the Zeiss RMK 1523 mapping camera shown in Fig. 1a was used in this project. A Zeiss intervalometer was used to provide the shutter trip pulses and adjustment of overlap on the baseline imagery. The associated Zeiss view finder allowed the aerial photographer to select the initial and final exposure points.

The multiband camera system consists of an array of four 70-mm cameras, an aircraft camera mount, a camera exposure command unit, and a view finder. The cameras must have a minimum film capacity of 15 ft, have automatic film advance and shutter cocking, and at least a 2 to 3 in. focal length lens. In addition, the dimensions of the cameras should be such that four cameras could be mounted in the aircraft camera window. Potential multiband cameras include the Fairchild type CAX-12, the Aerojet Delft TA-7M, the Hasselblad 500 EL/M, the Itek KA-61, and the Naval Air Development Center X70-7. The Hasselblad 500 EL/M camera with a 50 mm, f/1.4 Distagon lens satisfied all the requirements for the minimum price and was chosen for this project.

The cameras were attached to a rigid plate which was compatible with the aircraft mounting plate located in the camera window. The latter was adapted from the Zeiss camera assembly. The combination provided drift adjustment and leveling in two axes. The leveling was accomplished with a spirit level attached to the rigid plate. The camera mounting plate was fabricated from 0.25-in. aluminum plate. Four cameras were held by quick release mounts with the cameras oriented perpendicular to the plate, as shown in Fig. 1b. The camera command unit provided a relay for simultaneously activating all four cameras. The Zeiss aerial mapping view finder was used with the Hasselblad array.

The camera magazines hold the metal cassette that takes 15 ft of film which can provide seventy exposures. These cassettes are only for holding the film and have very poor light seals. This makes magazine loading in dark room conditions necessary. For inflight film loading in the cameras, a second set of magazines is required.

## Aircraft Requirements

The camera system dictates the aircraft requirements. A minimum image scale of 1:5000 was considered satisfactory for performing mensuration on the baseline photographs. For the mapping camera's 6 inch focal length lens, the image scale would be achieved for aircraft altitudes up to 2500 ft above ground level (AGL). Similarly, the scale for the Hasselblad camera photographs calculates to 1:9000 for an altitude of 1500 ft AGL. For the multiband analysis, this scale was considered minimal. At these altitudes, and for camera exposure times of 1/250 seconds, the aircraft ground speed should be approximately 110 to 120 knots to reduce image smear to an acceptable level. These ground speeds were also commensurate with the camera cycling rates. It should be pointed out that longer focal length lenses would allow higher altitudes and faster aircraft speeds. More sophisticated camera systems introduce an increase in cost.

For the aforementioned camera system, the aircraft must be capable of stable flight at 1500 ft AGL, and at ground speed of 110 to 120 knots. Camera accessibility during flight is needed for monitoring camera performance. The Aerocommander Model 680 and Cessna 336 aircraft used for this project are shown in Figs. 1c and 1d respectively. The Aerocommander satisfied all the aforementioned requirements, had a ceiling of 20,000 ft and a maximum flight time of 5-1/2 hours. The Cessna 336 satisfied all requirements with the exception of camera accessibility during flight. The Cessna's maximum ceiling was 10,000 ft and its maximum flight time was 5-1/2 hours.

## Flight Crew

The flight crew consists of the pilot, the aerial photographer and the camera monitor. The aircraft pilot should be qualified in aerial survey flight operations, including proficiency in the use of large scale maps (e.g., 1:24,000). He must be able to maintain the flight line to within - 3 deg and must be able to maintain the aircraft attitude while holding the flight line. The aerial photographer must have experience in aerial photography and be able to lay out the desired flight plan. Because of the possibility of camera failure, a third crew member should accompany each flight to monitor camera performance. If a camera malfunction does occur, the photographic run can be terminated, the malfunction remedied if possible, and the photographic run continued. This procedure requires more manhours per flight hour, but reduces total flight cost by improving the number of successful missions. Besides monitoring the camera performance, the camera monitor has an additional duty to look for and keep track of any other aircraft in the area. During a photographic run, the pilot is entirely occupied with the flight line and aircraft altitude and the photographer is totally occupied over the view finder. The camera monitor can continually maintain a lookout for other aircraft. This is especially important over a metropolitan area where the air traffic is heavy.

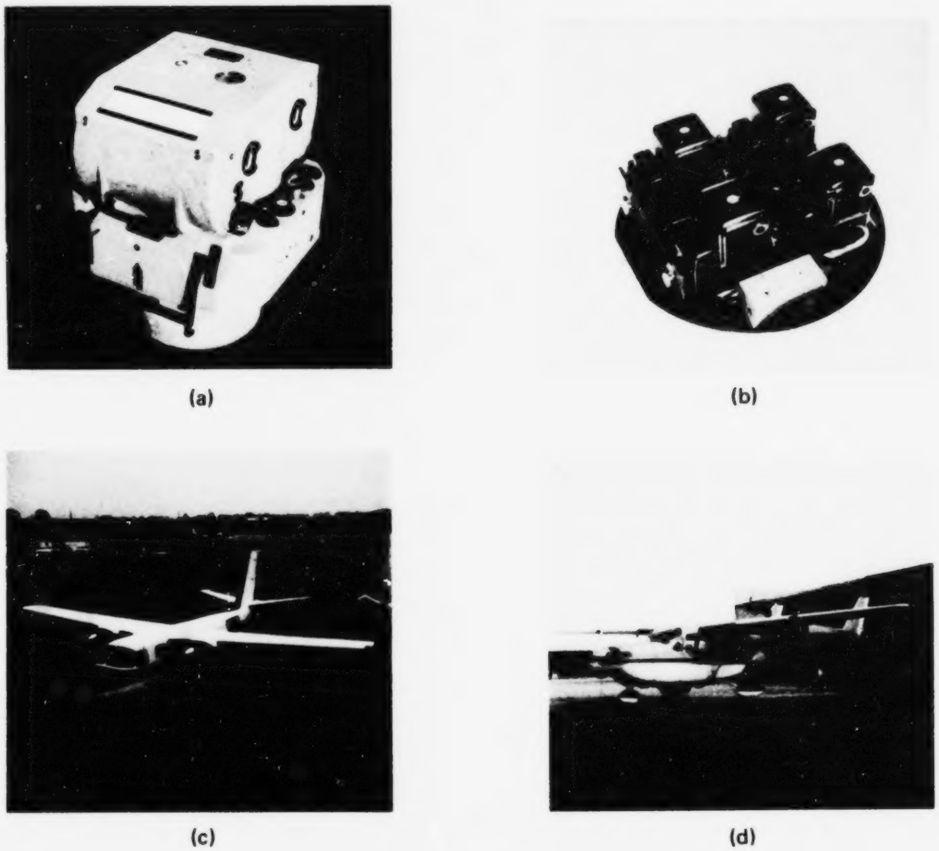

**Figure 1** Photographs of (a) Zeiss RMK 1523 camera, (b) Hasseblad camera array, (c) Aerocommander and (d) Cessna 336

## Filter Factors

Whenever a filter is placed in front of a camera system, the exposure (f/stop and exposure time) needed to achieve the same density as obtained without the filter can change drastically. The amount of this change depends primarily on the filter spectral transmittance, the film spectral sensitivity, and sunlight spectral characteristics. Over the period of this project, the sun's spectral characteristics do not change sufficiently to affect the filter factor. (From 27 July 1971 to 22 November 1971 the sun-zenith angle at local apparent noon varied from 17 to 50 deg.) Consequently, the solar energy must propagate through different atmospheric masses, so that the solar spectrum is affected in two ways. First, the total solar power per wavelength changes by approximately a factor of 3 over the specified time period. Second, there is an approximate 20% spectral power shift between 450 and 850 nm. Since the film's latitude allows satisfactory images to be recorded of objects whose incident power is a factor of 8 on either side of the best exposure, neither of these effects will significantly affect the filter factor.

After film types 2403, 2424, and 2475 were loaded in separate Hasselblad cameras, photographs of a gray scale and a color chart were taken outside at various f/stops, both with and without the nine filters used in this flight program. By comparing "normal" photographs to the filtered photographs taken at various f/stops, the f/stop correction for each film/filter combination was determined. Table 1 lists the f/stop correction (or filter factor) for each film/filter combination.

**Table 1 Filter factors**

| Filters | Film types | | |
|---|---|---|---|
| | 2403 | 2475 | 2424 |
| 18A | 3 | 3 | 2-1/2 |
| 39 | 1 | 1 | 1/2 |
| 47B | 2 | 2 | 1 |
| 32 | 1/2 | 1/2 | 1/2 |
| 35 | 1/2 | 1/2 | 1 |
| 65 | 2 | 2 | 1-1/2 |
| 75 | 4 | 4 | 1 |
| 98 | 2 | 2 | 1/2 |
| 99 | 3 | 3 | 1 |

Because the filter f/stop correction factors were determined on the ground rather than from aerial photographs, sometimes an additional 1/2 stop was needed to achieve the best image. The latitude of the film, however, allows satisfactory images to be obtained within 1 to 2 stops on either side of the best f/stop for similar atmospheric conditions. During hazy days, additional compensation of the exposure is needed and can be computed from an Aerial Index Exposure Calculator. Since almost all flights were made on clear or hazy days, complete experimental data is not available on the correction factors needed for other atmospheric conditions.

## Flight Parameters

Mission planning for the acquisition of aerial imagery is required for each new area to be photographed. A well-designed flight plan ensures the acquisition of a minimum amount of imagery which will be used to produce the required information concerning a specific area. The following factors were considered to define the flight plans used to acquire imagery for this project.

Film/Filter Combinations - The type of film and filter to be used is determined by the target and the purpose of the flight. In the baseline flights, a high resolution, black-and-white, stable base film and appropriate haze filter were required for mensuration work. In the multiband photography, the spectral signature of the target determined the most advantageous film and filter.

Imagery Scale Factor - The scale factor of a photograph is the ratio of the photo distance to the ground distance i.e., one inch on the photograph equals twelve hundred inches on the ground means a scale of 1:1200. For vertical photographs, scale is computed by dividing the aircraft altitude above ground by the focal length of the camera lens. This, along with the resolution capability of the film and camera, will determine the smallest object on the ground which can be recorded at the film plane. In this project it was decided that mensuration was to be performed using baseline imagery (high resolution) and tonal information was to be acquired using the multiband photography (less resolution).

Exposure Determination - The proper film exposure is computed by using the sun angle (latitude of target, time of year, and time of day), altitude (above ground level), film sensitivity (Aerial Exposure Index or Aerial Film Speed), shutter speed (in fractions of a second), ground haze conditions and film/filter combination. Shutter speed is then compared to aircraft ground speed to determine if the image smear (movement of image on film plane during exposure) is within allowable limits.

Flight Line Plan - The target is located and outlined on a map of the appropriate scale, typically 1:24,000 for an industrial area. The ground area within the field of view (FOV) of the camera for the selected flight altitude is plotted to scale and superimposed on the target area. If the width of the target is less than the frame coverage, only one flight line is required for that target. The center of the first frame is plotted on the map at the edge of the target area and all additional frame centers are plotted till the target length is covered. For stereo coverage of the target, the photographs should overlap by 60%. For monoscopic coverage, the overlap should be only 15% to assure continuous coverage.

If the target area is wider than the photograph, additional flight lines are plotted. The flight line overlap should be from 15 to 25%, depending on terrain elevation variation, wind conditions, and the pilot's ability to fly the indicated flight line.

Each target area requires a separate plan for proper coverage with a minimum of photographs. The flight lines with the beginning and end of the photographic run are plotted in a distinct color for easy reading. One copy is prepared for the pilot and one copy for the photographer.

Flight Plan Sheet - The flight plan sheet is a summary of the planning procedures used by the flight crew. It lists the mission number, camera settings, flight lines, selected altitudes, flight time, the names of the crew, date, number of exposures per flight line, heading, and time of completion of each flight line.

## Film and Filter Selection

Kodak Tri-X Aerographic film type 2403, Kodak Infrared Aerographic film type 2424 and Kodak Recording film type 2475 were used and evaluated in this project. Only the film type number rather than the descriptive title will be specified in this report. Kodak filters 18A, 47B, 39, 32, 35, 65, 75, 98, 99 and 25 were combined with the above mentioned films to determine the best film and filter combination for multiband identification of oil and hazardous material spills. The various film and filter combinations are specified film/filter. Hence the use of film type 2403 and filter 32 will be denoted 2403/32. The film and filter spectral characteristics along with their uses in multiband photography are discussed in Appendix A.

## Photographic Processing System

Precision photographic processing of the 70-mm multiband film and color film is necessary for the extraction of scientific data from the resultant images. Precision processing insures that the tonal variation in the multiband images is a result of the various targets' spectral reflectivities and not the result of fluctuation of the processing techniques. The essential parameters and their influence in determining the final precision processing system are discussed in detail in Appendix B.

# SECTION V

## EXPERIMENTAL PROGRAM

From 27 July 1971 to 22 November 1971, twenty-three flights were made over the St. Louis area. Three of these were baseline flights, while the remainder were multiband flights. The multiband flights were divided into two general areas: the oil refineries and the remaining industrial sites. This division was necessitated by the limited number of exposures (70) on each flight. The oil refinery industry was divided into eight aerial flight lines. The remaining six industrial areas were divided into nine aerial flight lines. Table 2 lists these flights and includes the general area, the flight date, the film/filter combinations on each camera, the filter corrected f/stops, exposure time, altitude, and overall performance. The last parameter only lists gross failures such as camera malfunctions and film fogging. Detailed image analysis is not included here.

Simultaneous ground truth measurements were made at least once at each industrial site while multiband missions were being flown. The parameters of interest were wet bulb and dry bulb temperatures, ground temperature, barometric pressure, sun angle, wind velocity and direction, and luminosity measurements in each of the spectral bands characterized by the filters flown on that mission. These measurements were made at two locations at each site. Table 3 lists these parameters recorded during the multiband missions and includes the site location, time, and date. Photographs of each location were taken on 35-mm Tri-X film with a Nikon camera with the same filters being flown. General correlation of the aerial multiband and ground imagery was observed.

## Table 2 Flight program

| Date | Altitude (ft) (above ground) | Flight area | Camera 1 | | | | Camera 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Film type | Filter | f# | Speed | Film type | Filter | f# | Speed |
| 27 Jul 71* | 2300<br>1300 | Oil refinery<br>Steel mill<br>Other industries | 2405 | #12 | 8 | 1/550 | | | | |
| 30 Jul 71* | 2500<br>2000 | Oil refinery<br>Other industries | 2448 | KLF | 5.6 | 1/275 | | | | |
| 14 Sep 71 | 1200<br>1200 | Oil refinery<br>Oil refinery | 2403<br>2475 | 47B<br>47B | 5.6<br>8 | 1/500<br>1/500 | 2403<br>2475 | 39<br>39 | 8<br>11 | 1/500<br>1/500 |
| 28 Sep 71 | 1200<br>1200 | Oil refinery<br>Oil refinery | 2403<br>2475 | 35<br>35 | 4<br>5.6 | 1/500<br>1/500 | 2403<br>2475 | 32<br>32 | 11<br>16 | 1/500<br>1/500 |
| 6 Oct 71 | 1500 | Oil refinery | 2403 | 18A | 5.6 | 1/500 | 2403 | 39 | 11 | 1/500 |
| 11 Oct 71 | 1500 | Oil refinery | 2403 | 65 | 8 | 1/500 | 2403 | 47B | 8 | 1/500 |
| 12 Oct 71 | 1500 | Oil refinery | 2403 | 75 | 4 | 1/500 | 2403 | 98 | 8 | 1/500 |
| 14 Oct 71 | 1500 | Oil refinery | 2475 | 32 | 22 | 1/500 | 2475 | 35 | 16 | 1/500 |
| 15 Oct 71 | 1500 | Oil refinery | 2424 | 18A | 6.3 | 1/500 | 2424 | 39 | 13 | 1/500 |
| 28 Oct 71 | 1500 | Oil refinery | 2424 | 32 | 13 | 1/500 | 2424 | 35 | 11 | 1/500 |
| 28 Oct 71 | 1500 | Oil refinery | 2424 | 75 | 9.7 | 1/500 | 2424 | 98 | 9.7 | 1/500 |
| 1 Nov 71 | 1500 to 2000 | Other industries | 2403 | 47B | 8 | 1/500 | 2403 | 39 | 11 | 1/500 |
| 2 Nov 71 | 1500 to 2000 | Other industries | 2403 | 35 | 16 | 1/500 | 2403 | 32 | 22 | 1/500 |
| 3 Nov 71 | 1500 to 2000 | Other industries | 2403 | 75 | 4 | 1/500 | 2403 | 98 | 8 | 1/500 |
| 3 Nov 71 | 1500 to 2000 | Other industries | 2475 | 47B | 8 | 1/500 | 2475 | 39 | 11 | 1/500 |
| 4 Nov 71 | 1500 to 2000 | Other industries | 2475 | 35 | 16 | 1/500 | 2475 | 32 | 22 | 1/500 |
| 4 Nov 71 | 1500 to 2000 | Other industries | 2424 | 18A | 6.3 | 1/500 | 2424 | 39 | 13 | 1/500 |
| 5 Nov 71 | 1500 to 2000 | Other industries | 2424 | 32 | 13 | 1/500 | 2424 | 35 | 11 | 1/500 |
| 10 Nov 71 | 1500 to 2000 | Other industries | 2424 | 75 | 11 | 1/500 | 2424 | 98 | 13 | 1/500 |
| 11 Nov 71 | 1500 to 2000 | Other industries | 2424 | 32 | 13 | 1/500 | 2424 | 35 | 13 | 1/500 |
| 11 Nov 71 | 1500 to 2000 | Other industries | 2424 | 18A | 6.3 | 1/500 | 2424 | 39 | 13 | 1/500 |
| 12 Nov 71 | 1500 to 2000 | Oil refinery | 2475 | 18A | 5.6 | 1/500 | 2475 | 39 | 11 | 1/500 |
| 22 Nov 71* | 3000 | Other industries | 2405 | #12 | 8 | 1/550 | | | | |

*Base flight – Zeiss camera

## Table 2 Flight program (cont.)

| Camera 3 | | | | Camera 4 | | | | Performance |
|---|---|---|---|---|---|---|---|---|
| Film type | Filter | f# | Speed | Film type | Filter | f# | Speed | |
| | | | | | | | | Good imagery |
| | | | | | | | | Good imagery |
| 2403 | 18A | 4 | 1/500 | 2448 | – | 4 | 1/250 | 2403 overexposed - |
| 2475 | 18A | 5.6 | 1/500 | 2448 | – | 4 | 1/250 | camera #4 malfunctioned |
| 2403 | 65 | 5.6 | 1/500 | 2448 | – | 4 | 1/250 | 2403 overexposed |
| 2475 | 65 | 8 | 1/500 | 2448 | – | 4 | 1/250 | cameras #1, #2 malfunctioned |
| 2403 | 47B | 8 | 1/500 | 2448 | – | 4 | 1/250 | Camera 3 out of focus and jammed |
| 2403 | 32 + .6 neu. den. | 16 | 1/500 | 2448 | HF3 | 5.6 | 1/250 | Camera #3 1 stop underexposed |
| 2403 | 99 | 5.6 | 1/500 | 2448 | HF3 | 5.6 | 1/250 | Good imagery |
| 2443 | 12<br>CC10M | 5.6 | 1/500 | 2403 | 32 | 22 | 1/500 | Good imagery |
| 2424 | 47B | 11 | 1/500 | 2424 | 25 | 11 | 1/500 | Camera #2 malfunctioned |
| 2424 | 65 | 9.7 | 1/500 | 2448 | HF3 | 5.6 | 1/250 | 2424 film fogged on some frames |
| 2424 | 99 | 8 | 1/500 | 2403 | 35 | 11 | 1/500 | Some fogging |
| 2403 | 18A | 5.6 | 1/500 | 2448 | HF3 | 5.6 | 1/250 | Camera #1 malfunction |
| 2403 | 65 | 8 | 1/500 | 2448 | HF3 | 5.6 | 1/250 | Good imagery |
| 2403 | 99 | 5.6 | 1/500 | 2403 | 47B | 8 | 1/500 | Good imagery |
| 2475 | 18A | 5.6 | 1/500 | 2448 | HF3 | 5.6 | 1/250 | Camera #2 jammed fixed in flight |
| 2443 | 12<br>CC10M | 5.6 | 1/250 | 2448 | HF3 | 5.6 | 1/250 | Good imagery |
| 2424 | 47B | 11 | 1/500 | 2424 | 25 | 11 | 1/500 | All lost because of film fogging |
| 2424 | 65 | 9.7 | 1/500 | 2424 | 99 | 8 | 1/500 | All lost because of film fogging |
| 2424 | 99 | 11 | 1/500 | 2448 | HF3 | 5.6 | 1/250 | Good imagery |
| 2424 | 65 | 9.7 | 1/500 | 2443 | 12<br>CC10M | 5.6 | 1/250 | Good imagery |
| 2424 | 47B | 11 | 1/500 | 2403 | 47B | 8 | 1/500 | Good imagery |
| 2475 | 47B | 8 | 1/500 | 2424 | 39 | 13 | 1/500 | Good imagery |
| | | | | | | | | Good imagery |

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## Table 3 Simultaneous ground truth data

| Industry | Date | Location | Time | Wet bulb temp. | Dry bulb temp. | Ground temp. |
|---|---|---|---|---|---|---|
| | | | | °F | °F | °F |
| Oil refinery | 14 Sep 71 | Oxidation ponds | 11:40 a.m. | 72.5 | 87.0 | 85.0 |
| | | Bulk storage area | 12:10 p.m. | 70.0 | 86.0 | 95.0 |
| Oil refinery | 28 Sep 71 | Loading area | 1:25 p.m. | 77.0 | 87.0 | 93.0 |
| | | Oil waste ponds | 2:00 p.m. | 78.0 | 92.5 | 87.0 |
| Cement plant | 1 Nov 71 | Shale quarry | 1:10 p.m. | 68.0 | 77.0 | 72.0 |
| | | Effluent | 1:45 p.m. | 68.0 | 78.0 | 73.5 |
| Chemical plant | 2 Nov 71 | Water tower | 11:05 a.m. | 57.0 | 67.0 | 65.5 |
| | | Benzene tank | 11:16 a.m. | 56.0 | 67.0 | 66.5 |
| Titanium plant | 2 Nov 71 | Railroad track adjacent river | 1:12 p.m. | 56.5 | 70.0 | 83.0 |
| | | Storage area | 1:30 p.m. | 56.0 | 70.0 | 54.0 |
| Power plant | 3 Nov 71 | Effluent | 11:20 a.m. | 50.0 | 61.0 | 66.0 |
| | | Fly ash pond | 11:45 a.m. | 50.0 | 59.5 | 60.0 |
| Sewage plant | 4 Nov 71 | Effluent | 11:20 a.m. | 52.0 | 62.0 | 68.0 |
| Steel mill | 5 Nov 71 | Large pond | 9:45 a.m. | 52.0 | 64.0 | 59.0 |
| | | Final pond | 10:30 a.m. | 49.0 | 64.0 | 64.0 |

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## Table 3 Simultaneous ground truth data (cont.)

| Sun angle (deg) | Wind velocity and direction | | Barometric pressure (in.) | Spectral luminosity | | Weather conditions |
|---|---|---|---|---|---|---|
| | mph | direction | | Filter | Foot candles | |
| 51.0 | 0 | | 30.02 | None | 6000 | Slight haze |
| | | | | 47B | 390 | |
| | | | | 39 | 875 | |
| | | | | 18A | 260 | |
| 54.0 | 2.0 | SW | 30.04 | None | 6000 | Slight haze |
| | | | | 47B | 390 | |
| | | | | 39 | 875 | |
| | | | | 18A | 260 | |
| 48.0 | 4-10 | S | 30.16 | None | 6000 | Clear |
| | | | | 35 | 1500 | |
| | | | | 32 | 3500 | |
| | | | | 65 | 500 | |
| 49.0 | 10-12 | S | 30.13 | None | 6000 | Clear |
| | | | | 35 | 1500 | |
| | | | | 32 | 3500 | |
| | | | | 65 | 500 | |
| 33.0 | 6 | SSW | 30.04 | None | 7000 | Partially cloudy |
| | | | | 18A | 390 | |
| | | | | 39 | 1000 | |
| | | | | 47B | 390 | |
| 30.0 | 2 | SSW | 30.03 | None | 2000 | Cloudy |
| | | | | 47B | 113 | |
| | | | | 39 | 260 | |
| | | | | 18A | 113 | |
| 37.0 | 2-4 | W | 31.70 | None | 6000 | Clear |
| | | | | 35 | 1500 | |
| | | | | 32 | 3500 | |
| | | | | 65 | 500 | |
| 36.5 | 11 | W | 31.70 | None | 6000 | Clear |
| | | | | 32 | 3500 | |
| | | | | 35 | 1500 | |
| | | | | 65 | 500 | |
| 33.0 | 0-4 | SW | 31.20 | None | 6000 | Clear |
| | | | | 32 | 3500 | |
| | | | | 35 | 1250 | |
| | | | | 65 | 500 | |
| 31.5 | 0-2 | SW | 31.40 | None | 6000 | Clear |
| | | | | 32 | 3500 | |
| | | | | 35 | 1250 | |
| | | | | 65 | 500 | |
| 35.0 | 10-12 | SW | 30.34 | None | 6000 | Clear |
| | | | | 18A | 260 | |
| | | | | 47B | 390 | |
| | | | | 39 | 875 | |
| | | | | 75 | 390 | |
| | | | | 98 | 390 | |
| | | | | 99 | 750 | |
| 36.0 | 20-30 | SW | 30.30 | None | 6000 | Clear |
| | | | | 18A | 260 | |
| | | | | 39 | 875 | |
| | | | | 47B | 390 | |
| | | | | 75 | 390 | |
| | | | | 98 | 325 | |
| | | | | 99 | 750 | |
| 36.0 | 3-6 | SSE | 30.32 | None | 7200 | Clear |
| | | | | 18A | 312 | |
| | | | | 39 | 1000 | |
| | | | | 47B | 390 | |
| | | | | 32 | 4000 | |
| | | | | 35 | 1500 | |
| 21.0 | 12 | ESE | 31.90 | None | 6000 | Clear Scattered clouds |
| | | | | 32 | 3250 | |
| | | | | 35 | 1500 | |
| | | | | 65 | 625 | |
| | | | | 99 | 750 | |
| 25.0 | 8-10 | ESE | 32.00 | None | 6000 | Clear Scattered clouds |
| | | | | 32 | 3500 | |
| | | | | 35 | 1500 | |
| | | | | 65 | 500 | |
| | | | | 99 | 750 | |

# SECTION VI

# IMAGE ANALYSIS

## Technique

From the 17 aerial flight lines, 20 individual areas covered with one to three 70-mm frames were chosen for detailed multiband image analysis. The best image or images were chosen for each film type.

The best film/filter combinations were then chosen by comparing the best filtered images recorded. These images were grouped into general categories, such as bulk storage areas, effluents, waste lagoons, etc., and resulting best film/filter combinations were compared and evaluated. The multiband image evaluations contained in this report are based on an examination of the original transparencies and not on the prints contained herein. Baseline photographs were chosen of the same categorical areas for detailed mensuration work.

The information obtainable from the baseline photographs, the value of multiband imagery and the best film/filter combinations, and the value of thermal infrared imagery extracted from our data base are discussed for each area.

The imagery recorded on film types 2475 and 2443 is not mentioned in the multiband imagery discussion. The 2475 imagery was found to have less contrast than the 2403 imagery and was eliminated as a multiband imagery film. The slight increased ultraviolet sensitivity of film type 2475 was offset by its lack of contrast. The imagery recorded on film type 2443 was found to be unique in its color scheme and emphasizes vegetation detection. Straight color imagery obtained with film type 2448 offers as much in contrast and detection capabilities as film type 2443 for the areas under consideration.

## Oil Tank Storage

The baseline imagery shown in Fig. 2 is typical of a large oil tank storage area and shows many of the features of this type of installation. While this area is located 2 1/2 miles east of a major river, it does not constitute a real threat. The value of examining this major storage area is the application of this analysis to similar areas located adjacent to an inland waterway which could constitute a real or potential threat.

The overall slope of the ground in Fig. 2 is to the northeast or lower left corner of the photograph. The drainage is to a swampy area (not shown in the photograph) with no apparent outlet. At the center of the image, labeled A, there is a complex of waste ponds, with roads for

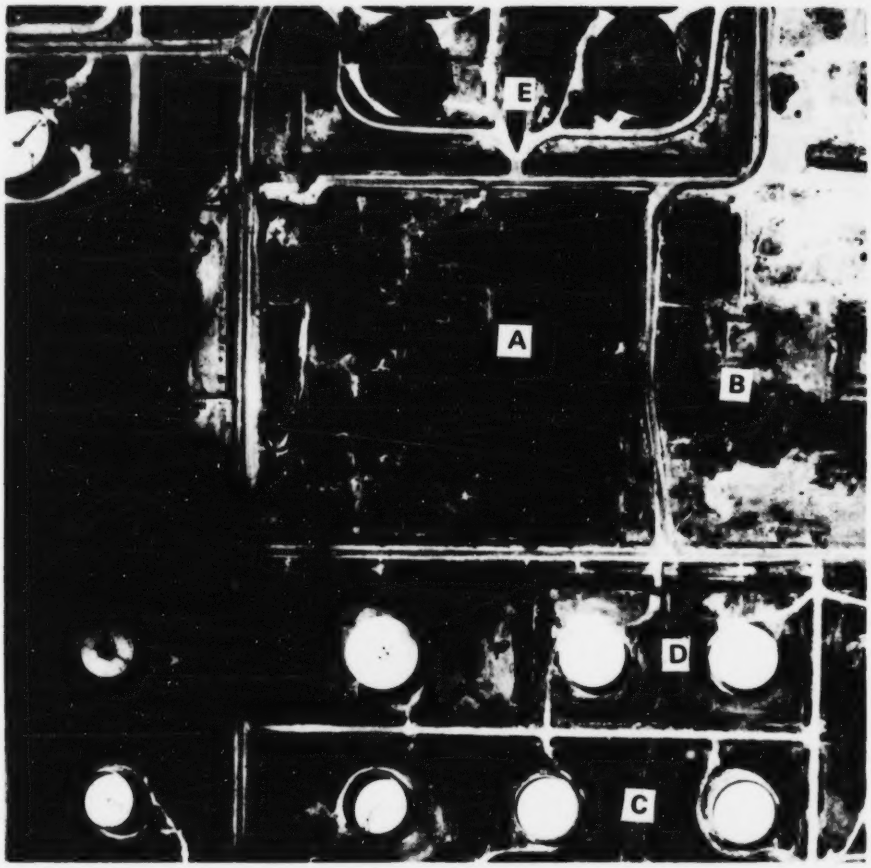


Figure 2 Baseline imagery of oil tank storage

dumping and removing waste material. The area has been used to dispose of waste containing considerable solid material. The dikes are approximately 5 ft high, and, in some cases, the precipitated solid matter has completely filled the ponds, and would constitute a potential threat if located adjacent to an inland waterway. At point B is a square-shaped area where the dike is only approximately 3 ft high. This area does not represent a threat as it only encloses a flare which is part of the safety system used for the burning of gasses during plant emergencies.

The row of tanks, marked C, are of the floating roof variety used to store gasoline. These tanks have a diameter of 128 ft and a height of 43 ft to the upper rim. They are easily identified by the walkway extending from the rim to the center of the top of the tank. No other type of tank is equipped with this type of walkway or control arm. The tanks on the left end of row D are similar but smaller. The remaining three tanks of row D are of the fixed-top (cone roofed) variety used to store less volatile products such as kerosene and jet fuel. An identifiable feature is the venting fixture located on the top of the tank. The two tanks on the right are approximately 39 ft high and have a diameter of 128 ft. The remaining tank is approximately 145 ft in diameter and 43 ft high.

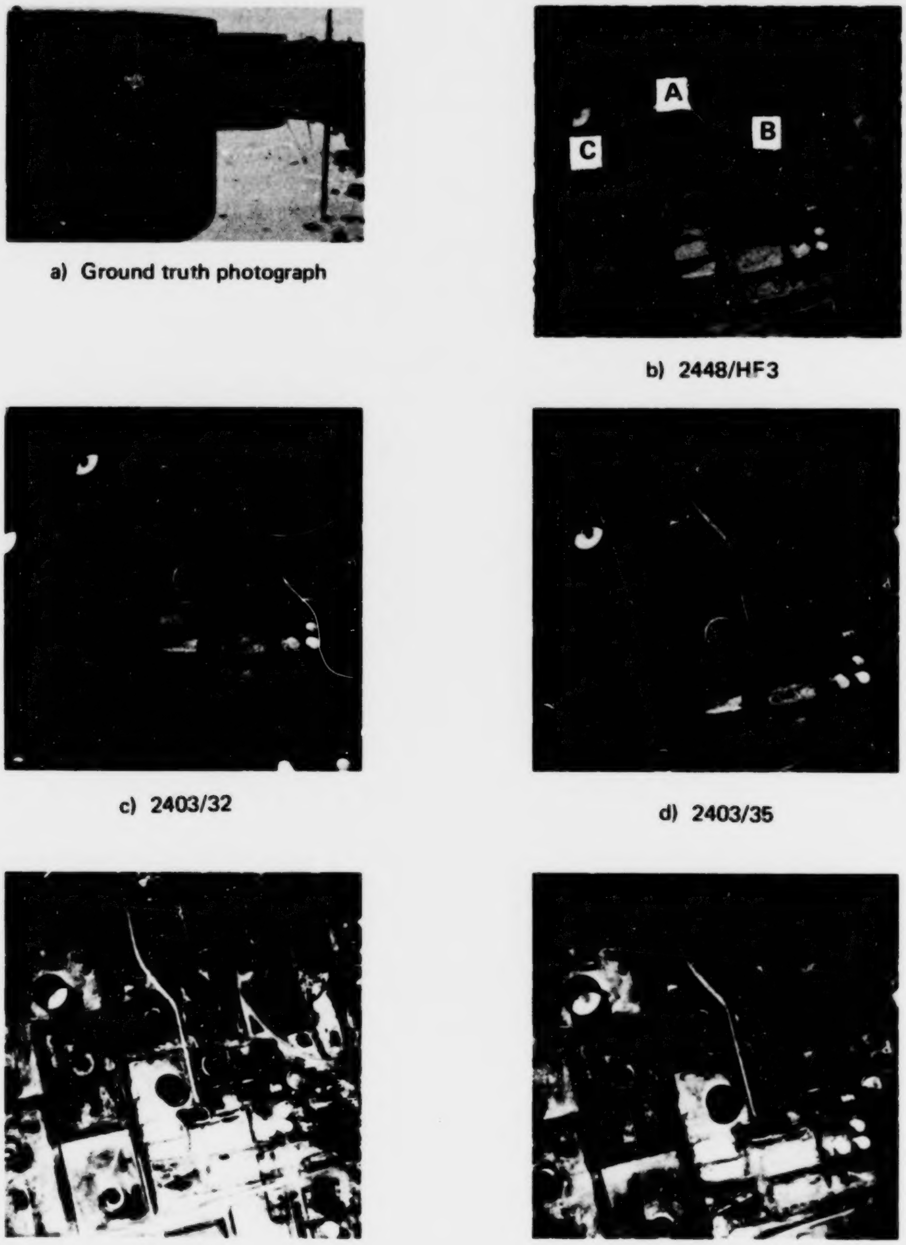
The two tanks at the top of the image, marked E, are the largest in the immediate area. They are approximately 158 ft in diameter and 48 ft high and are the only tanks in the photograph that employ above ground piping in the revetted area.

The protective revetments are generally 5 to 6 ft high, and are in good repair. From the stereoscopic analysis, the volume of the diked area is sufficient to hold the volume of the tanks under consideration. The enclosed area around the tanks appears to be well maintained and includes service roads to each tank. These areas all show some signs of vegetation and no distinguishable accumulation of spillage. No trash or debris can be found in the enclosed diked areas. In general, the tank farm would not constitute a potential threat even if it were located adjacent to an inland waterway.

Multiband flights were flown over a bulk storage area for asphalt and residual fuel oil. Asphalt and residual fuel oil storage can be identified by black, sealed-roofed, round tanks. A ground truth photograph of such a tank obtained on an initial ground truth mission is shown in Fig. 3a. Figure 3b is a 70 mm aerial color photograph of the asphalt bulk storage area. This area is also located approximately one mile from the major waterway and does not directly represent a potential or real threat. The value of the multiband flights in this area was in the positive identification of asphalt spills through contrast enhancement. These results can be applied to other areas adjacent to an inland waterway in order to determine whether an undefined spill, and thus the spill source, constitutes a real or potential threat.

Positive ground asphalt spills are noted in areas A, B and C. Ground truth teams had identified a leaky asphalt tank in this area. Figures 3c to 3f are photographs of the bulk storage area recorded with film/filter combinations 2403/32, 2403/35, 2424/35, and 2424/99, respectively. There appears to be little difference between the use of filter 32 and filter 35 with either film type 2403 of type 2424. A look at the spectral responses of these filters shows that filter 32 passes more of the visible spectrum (300 to 520 nm) than filter 35 (320 to 460 nm). Since oil and asphalt have a strong reflectance in the ultraviolet and blue spectral regions, the asphalt imagery obtained with filter 32 is expected to be slightly darker than that obtained with filter 35 as evidenced in Figs. 3c and 3d. A comparison of Figs. 3d and 3e reveals that better asphalt-to-background contrast is achieved with film/filter combination 2424/35 than with 2403/35. This is due to the near-infrared (700 to 850 nm) background return recorded by film type 2424.

The maximum asphalt-to-background contrast is observed on imagery recorded with film/filter combination 2424/99 as shown in Fig. 3f. Although



a) Ground truth photograph

b) 2448/HF3

c) 2403/32

d) 2403/35

e) 2424/35

f) 2424/99

Figure 3 Asphalt bulk storage area

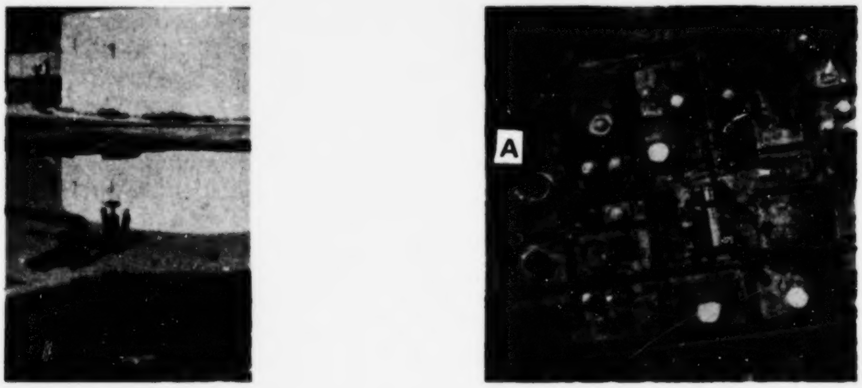
definition or detail is lacking in the spilled areas, the asphalt appears very dark against a light background. Since the 99 filter only passes the yellow portion of the spectrum (500 to 600 nm), any return from the asphalt in the ultraviolet and blue region of the spectrum has been suppressed. Filter 99, however, does pass the 700 to 850 nm radiation to which film type 2424 is sensitive. Because the asphalt appears very dark in this imagery, it was concluded that asphalt reflects little radiation in this spectral band. The contrast of asphalt to the background has been increased by suppressing the asphalt reflected radiation. This phenomena has been termed negative contrast enhancement. It was therefore concluded that the film/filter combination 2424/99 best detects asphalt against the ground background. Film/filter combinations 2424/35, 2403/35 and 2403/32, however, give better definition of asphalt spilled in water.

In the oil refinery bulk storage area, highly volatile gasoline products are stored in white floating top tanks. The gasoline is treated with caustic soda to improve the odor and to stabilize the final product. The gasoline can acquire a variety of colors, depending on the additives and amount of volatile material removed. On a particular ground truth mission, gasoline that had a reddish appearance, was spilled in a diked area as shown in Fig. 4a. A color aerial photograph of this area covered during the multiband flights is shown in Fig. 4b. The dike in which this gasoline spill is observed is marked A. This area is also located approximately 1.2 miles from the river and does not represent a threat to the waterway. The value of the multiband flight in this area is the determination of a film/filter combination that allows positive identification of gasoline. These results are directly applicable to areas adjacent to an inland waterway. An undefined spill can be positively identified as gasoline and the source sought in the imagery to determine if a real or potential threat to the waterway exists.

The two best film/filter combinations for gasoline detection were found to be 2403/99 and 2403/65, as shown in Figs. 4c and 4d, respectively. Film/filter combination 2403/65 imagery shows better contrast enhancement of this area than 2403/99. Again, negative enhancement is emphasized by suppressing the gasoline reflected radiation and making the area of interest appear dark. Even though filter 65 passes a broader portion of the spectrum (440 to 580 nm) than filter 99 (500 to 600 nm), it is more effective in the negative enhancement technique as it blocks out the near-red spectral region.

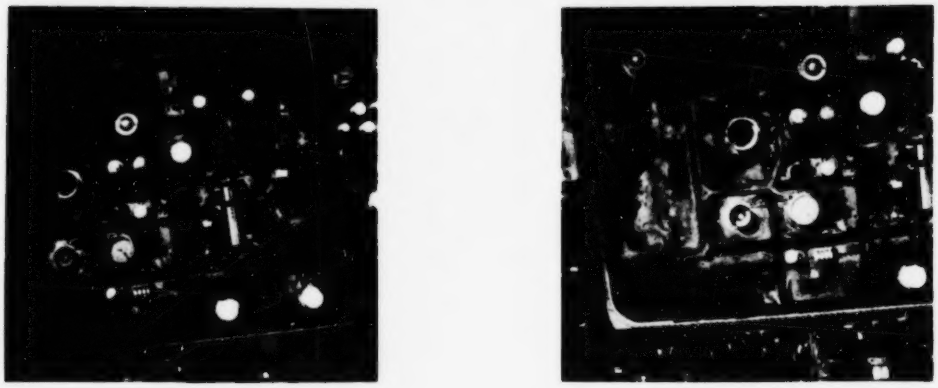
### Titanium Plant Bulk Storage

The titanium plant has many tanks which are primarily used for processing. The larger tanks shown in Fig. 5 are for bulk storage. In addition to these tanks, a large fuel oil tank is located to the south of the facility. The tanks marked A in Fig. 5 are for liquid sulfur storage. These three tanks are easily identified by the heating tube tops which appear as light dots around the tank circumference. A walkway around



a) Ground truth photograph

b) 2448/HF3



c) 2403/99

d) 2403/65

Figure 4 Gasoline bulk storage area

the tank tops and an interconnecting walkway between tanks are also evident. The tanks measure approximately 32 ft from the ground to the base of the dome and have a diameter of 41 ft. The volume of these tanks is estimated at 7500 bbls. The tanks appear well cared for and no seepage or leakage were observed. A ground truth team learned that a 3 ft high dike, not evident in Fig. 5, is located adjacent to the river along the plant boundary line. There are no control dikes around the tanks which would drain to the river if ruptured. Molten sulfur, however, would solidify at ambient temperature and impede its own flow. The effectiveness of the sulfur solidification as a protective measure is unknown. This area, therefore, represents a potential spill threat to the inland waterway.

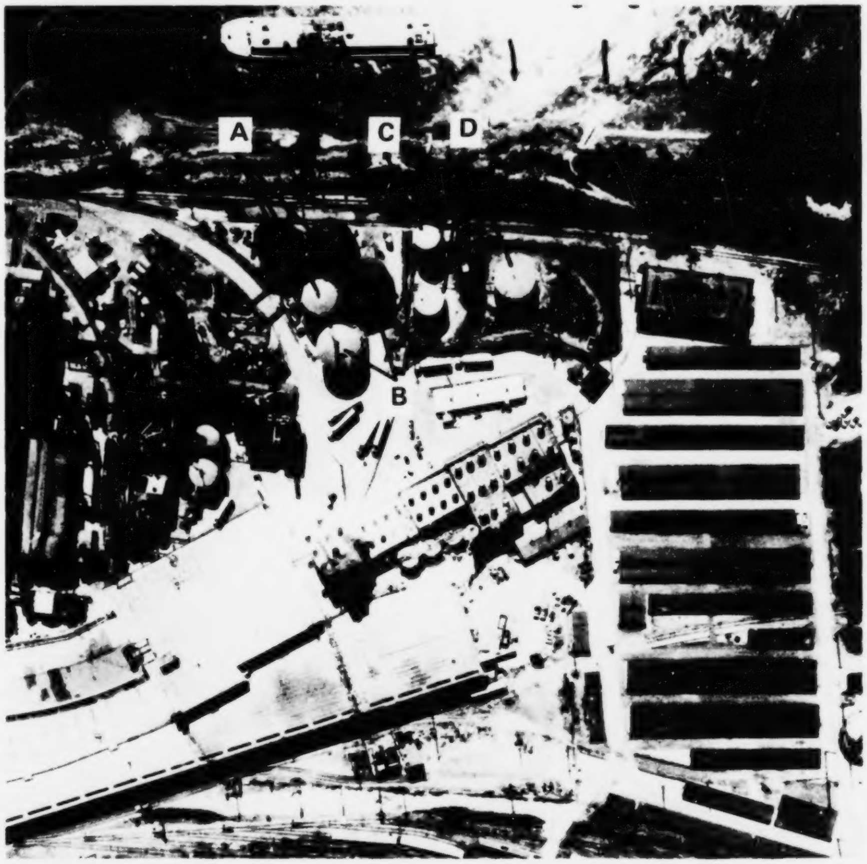


**Figure 5 Baseline imagery of titanium plant tank storage**

The two tanks labeled B are used to store sulfuric acid. They measure approximately 54 ft in diameter and 32 ft from the ground to the base of the domed top. Their volume is estimated at 13,000 bbls. each. These tanks appear well cared for, but are unrevetted and would drain to the river if ruptured. The ground truth team also learned the tanks are connected through pipeline to four additional acid storage tanks within the plant should they leak or rupture.

The tank labeled C is used to store sodium hydroxide and is approximately 35 ft in diameter and 24 ft high. The tank volume is approximately 4100 bbls. The tank appears well cared for, but is undiked and would drain to the river if ruptured. A ground truth team learned that this tank is also connected to additional storage tanks within the plant should it leak or rupture.

The tanks labeled D, are used for fuel oil storage. The larger tank measures 50 ft in diameter, 23 ft high, and has a capacity of 8000 bbls. It is in good condition and is enclosed by a 5 ft high dike which is adequate to hold the tank's contents. The area is clean and appears to have foliage in part of the diked area. The smaller tank is approximately 35 ft in diameter, 24 ft high and has an estimated volume of 13,000 bbls. This tank appears well cared for and is enclosed by a 5 ft high dike sufficient to hold the tank's contents.

Baseline flights over bulk storage areas were effective in determining the number of tanks, the material in the tanks, the structural condition of the tanks, the use of control dikes, the type of piping in these areas, the presence of debris in diked areas, and any seepage or leaks around tank storage.

The value of multiband imagery is in establishing the spectral characteristics and identifying the material that has been spilled or leaked in the storage area. Once the material has been identified, the source can be located and the potential or real threat to the waterway determined. In the titanium industrial area, no spills were found in the bulk storage area on the multiband and color imagery. The effectiveness of multiband imagery in this area could not be positively confirmed. Color photography was concluded to be an essential part of the aerial surveillance system for the detection of spills and spill sources.

## Chemical Plant Storage

The part of a chemical plant shown in Fig. 6 is a storage area dominated by the benzene storage tank. The floating top tank is approximately 105 ft in diameter and 30 ft high. In this photograph, the floating tank top has descended approximately half way down the tank. The tank volume is estimated at 52,000 bbls. The tank is surrounded by an 8 ft high cement dike enclosing an area 286 ft long and 153 ft wide. The area is clean and well tended although there was evidence of a liquid, which could be water, on the ground. One major and one minor pipeline are connected to the tank and run above ground.

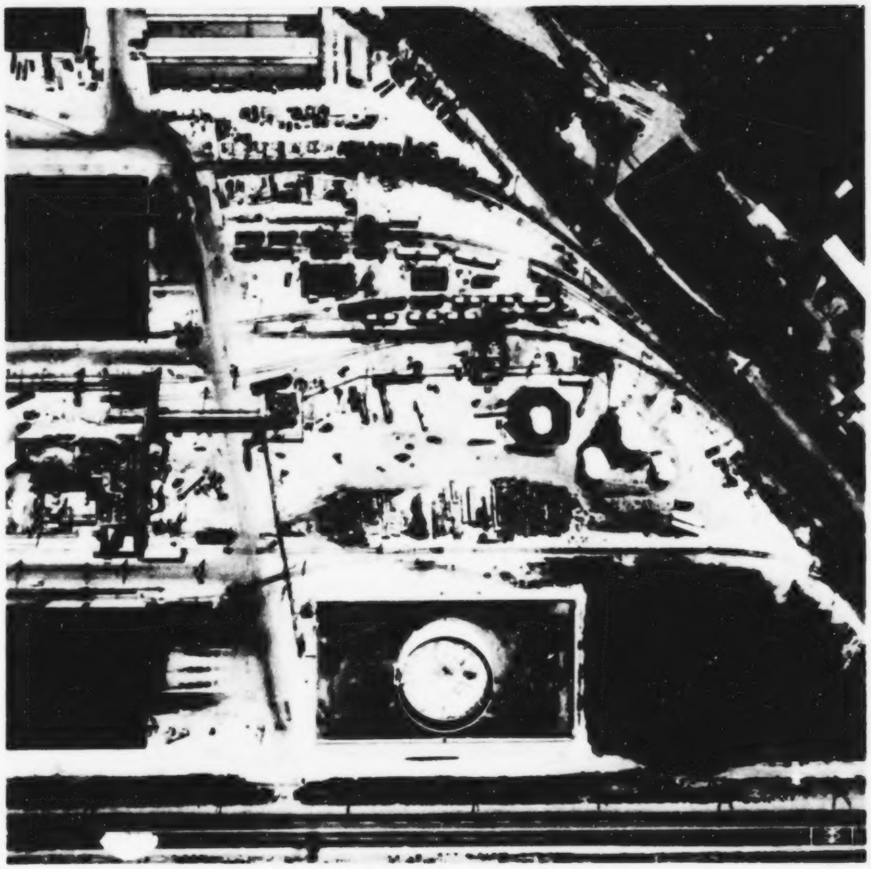


Figure 6 Baseline imagery of chemical plant tank storage

The river is located 4200 ft from the bottom of the photograph and the terrain is flat with no specific drainage pattern. In addition, the chemical industry is located behind a protective levee and therefore does not represent a direct threat to the inland waterway. Drain gates, which connect directly to the river through storm sewers, are evident throughout the chemical plant and are used for the emergency disposal of spilled hazardous materials. A close examination of such an area discloses an indirect potential threat to the inland waterway.

Multiband imagery only has value in determining the type of spills and in helping to better define drainage patterns. Over the chemical facility, however, very few spills were located (one is described under loading facilities). The effectiveness of multiband photography could not be readily assessed in this area. Generally it appears that these spills are easily defined with color photography and a knowledge of the type of material stored in specific tank types.

## Steel Mill Waste Storage Lagoons

In the steel industry, waste storage lagoons contain a variety of materials. Such materials include lubricating oil from the rolling mill cooling system, rust or iron which is acidicly removed from stored steel materials, and water from various cooling towers. The cooling water contains chemicals that are used to eliminate scale and fungus from the cooling towers. The lagoon that contains the above materials is treated with caustic soda to neutralize the acid and settle out solids (iron scale) and is then passed through a filtration pond before it is exited into the river.

The lagoon shown in Fig. 7 is located within the plant area of a large steel mill. The liquid flow is from the right of the imagery to the left. The lagoon was made by excavating four parallel trenches approximately 350 ft long, 70 ft wide, and 40 ft apart. The drain is connected to the lower end on the first trench. Starting at the right, number one and two trenches are connected at the top, number two and three trenches at the bottom, and number three and four trenches at the top. The drain-off trench is located at the lower end of trench number four.

At the time the image was recorded, number one and two trenches were connected at their midpoint with the upper portions dammed off from the lower portion. This was probably done to facilitate the removal of sediments from the trenches. Footbridges and a chemical additive processor can be seen at the lower right end of the complex. At a later date, other sections of the system will probably be closed off for maintenance.

Multiband flights were conducted over the steel mill waste lagoons to determine the best film/filter combination for material identification. These results could then be applied to similar areas located adjacent to inland waterways to identify and thus locate potential and real spill sources threatening the inland waterway. The details of the multiband analysis are given in Appendix C. For this area, color photography revealed more information than any of the multiband images.

From the final steel mill drainage lagoon, the waste is channelled into an impounding area in which other industrial complexes also dump waste materials. Identification of all the dumped materials was not possible because of the many companies involved. From the impounding area, the material drains by a creek or canal to two sixty inch mains located beneath the river dike, which empty directly into the Mississippi River. This drainage constitutes an actual or real threat to inland waterway. A valve in this main prevents water from backing up into the impounding area during high water. A ground truth photograph of the canal is shown in Fig. 8a. An aerial color photograph of this canal

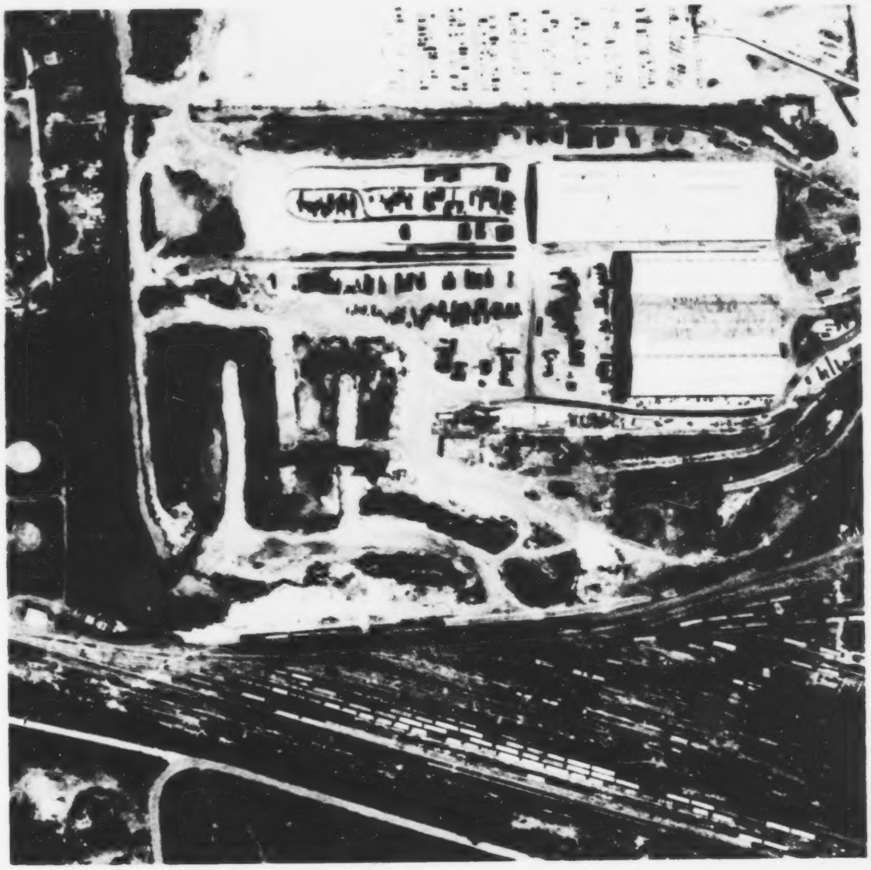
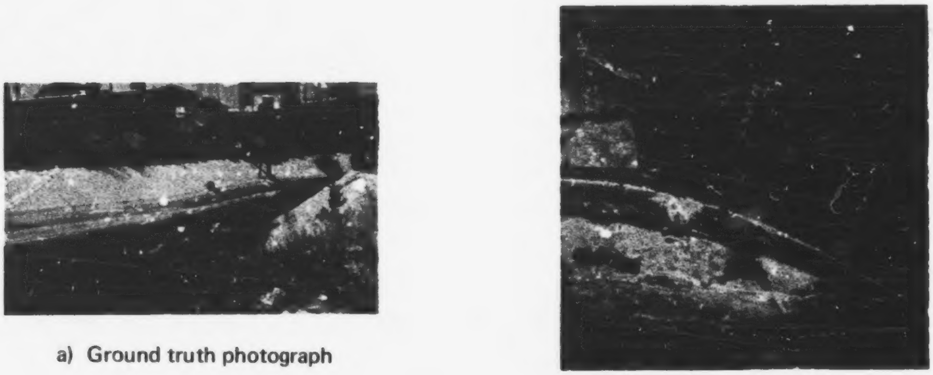


Figure 7 Baseline imagery of steel plant waste lagoon

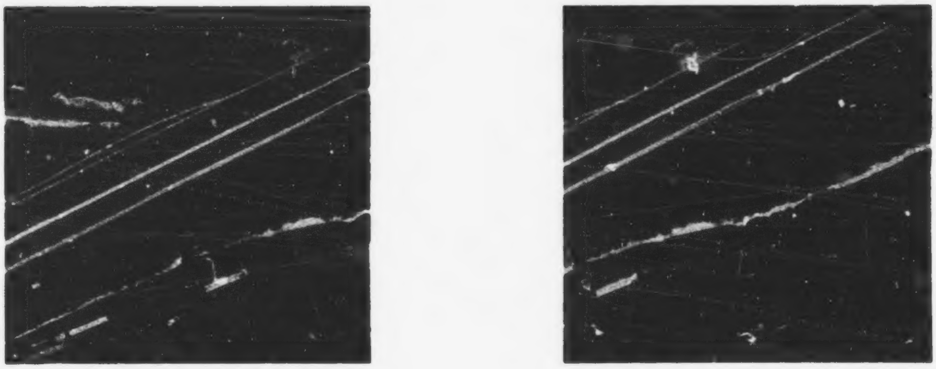
before it reaches the river levee is shown in Fig. 8b. Figure 8c is an aerial color image of the effluent passing under the levee, and Fig. 8d shows the dissipation of the waste in the river.

The drainage pattern of this area was determined from the baseline image shown in Fig. 9. The waste flow begins from the upper left of the photograph and extends to the lower right. Additional drainage channels can be observed in the upper right of the image. The entire area is behind a flood control dike which runs parallel to the river. The area is covered with revetted waste lagoons which are not presently being used. Some foliage has returned to the area. A solid waste dump can be seen in the dark areas in the upper right of the photograph.



a) Ground truth photograph

b) Drainage to river



c) Effluent under levee

d) Waste dissipation in river

**Figure 8 Steel mill and adjacent industrial waste drainage**

In Fig. 8, the black color of the waste indicates the presence of oil. The multiband imagery confirms the nature of waste material. Multiband photography is valuable for identifying the effluent material to determine if a real threat to the waterway exists. The best contrast was obtained on imagery recorded on film/filter combinations 2403/99, 2403/35, 2424/99 and 2424/35. The images obtained are shown in Figs. 10a, 10b, 10c, and 10d, respectively. These same film/filter combinations were found to be effective for oil and asphalt detection. In examining Figs. 10a to 10d, one concludes that filter 99 with both film types 2403 and 2424 gives better contrast of the oil to background than filter 35 because of its suppression of the oil reflectance in the ultraviolet, blue, and red portions of the spectrum. Here again, negative contrast enhancement is emphasized. Filter 32, which transmits these

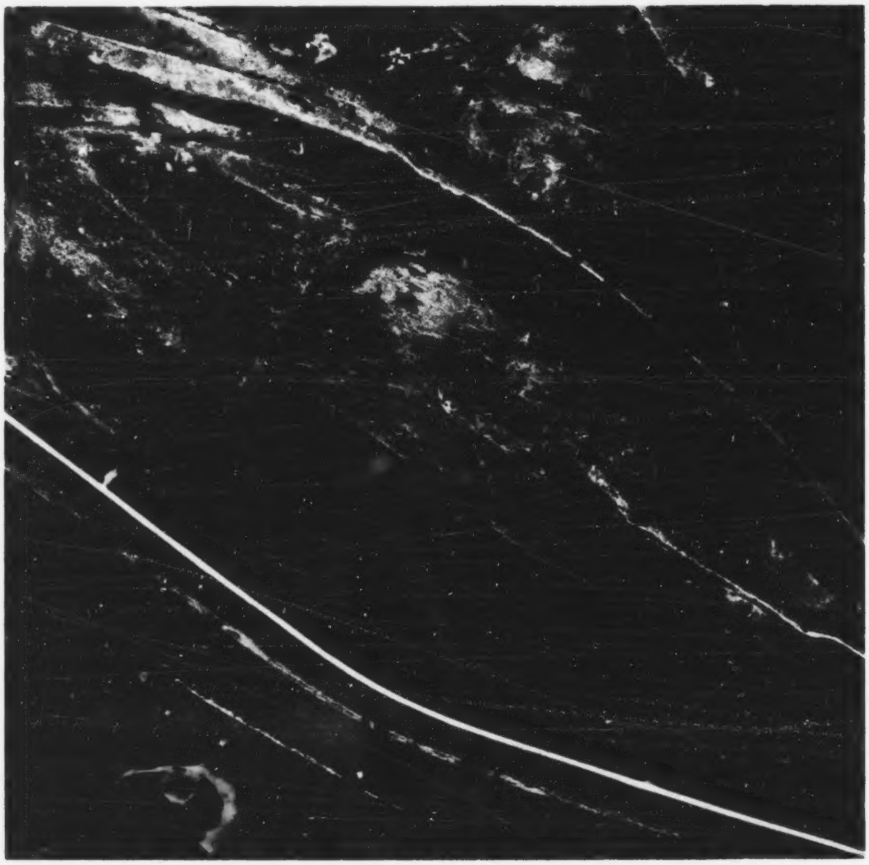
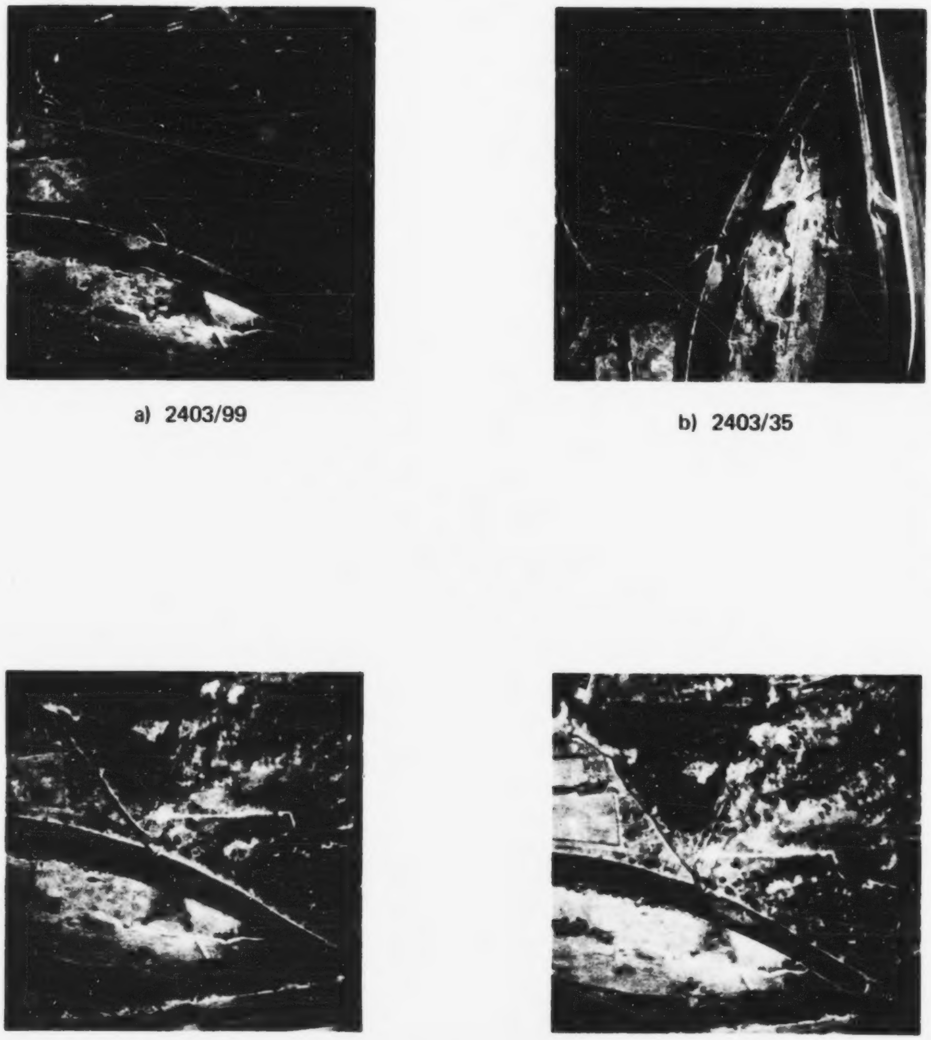


Figure 9 Baseline imagery of steel plant and adjacent industrial waste drainage

spectral regions, results in reduced image waste background contrast but increases the detail. Film/filter combination 2424/99 gives better contast of the drainage area to the background than film/filter combination 2403/99 because it records more near-infrared radiation reflected from the ground and vegetation. However, in the detection of oil in water, the near-infrared absorption of water reduces the oil water contrast.



a) 2403/99

b) 2403/35

c) 2424/99

d) 2424/35

Figure 10 Steel mill and adjacent industrial waste drainage

Figure 11 is a thermal infrared image of the drainage pattern observed near the steel mill discussed above. The drainage creek is shown as a white area, indicating that its temperature is higher than the background. A temperature increase could be the result of the temperature at which the waste is discharged from the industrial area, or of the absorption and reradiation properties of the waste material. The value of thermal infrared imagery is the detection of pollutant materials warmer than their surroundings.

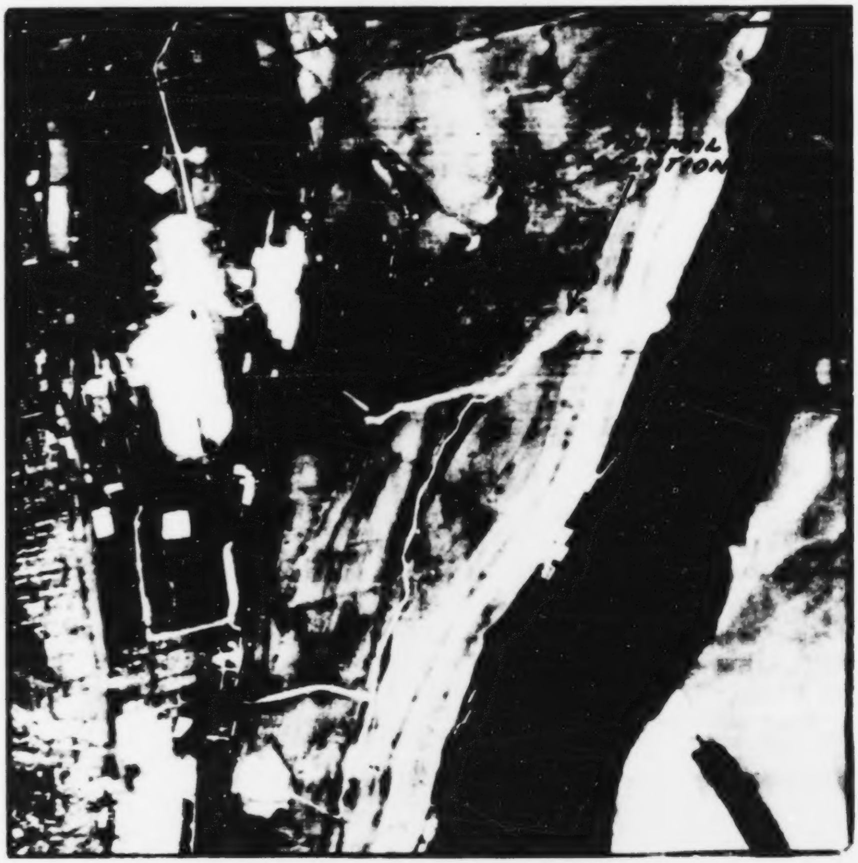


**Figure 11** Thermal infrared image of steel mill and adjacent industrial waste drainage

Power Plant Fly-Ash Pond

Another type of waste lagoon identified during this project is the fly-ash pond located adjacent to a power plant. Figures 12a and 12b are ground truth and aerial photographs of this fly-ash pond, respectively. The fly-ash residue from the boiler is transported to the pond by water. The water flows into the pond at the dark area and settles out.

By the time the water moves to the overflow on the opposite side of the pond, which empties into the river, almost all solid matter has settled out. The pond does not constitute a threat to the inland waterway. The pond covers approximately 34 acres, with less than one-third being covered by water level deposites of fly-ash.

Generally, ash piles are a black to dark gray color. The maximum contrast of the ash pile to the pond was obtained on imagery recorded with film/filter combination 2403/99 as shown in Fig. 12c. The ash pile appears very dark as filter 99 suppresses the reflected radiation. For comparison, the imagery obtained with film/filter combination 2424/65 is shown in Fig. 12d. As can be seen, the fly-ash pile pond contrast is not as great as that obtained with film/filter 2403/99. This is a result of water absorption in the near-infrared region recorded by film type 2424. The advantage of the multiband imagery is in identifying drainage patterns in the pond that are not apparent in color imagery.

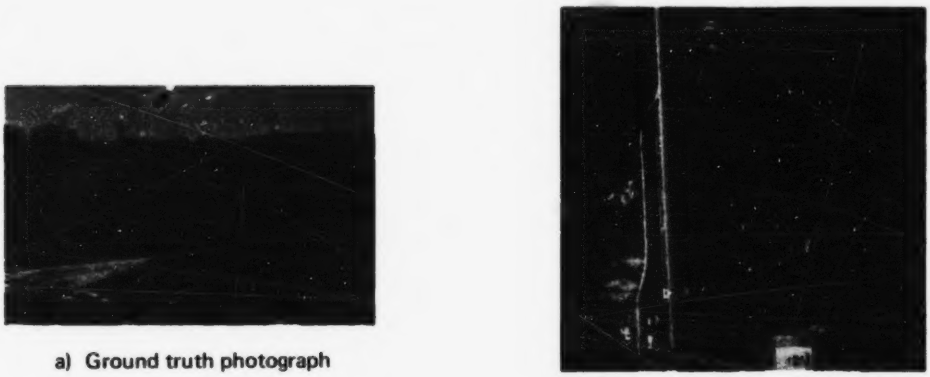
### Waste Treatment Ponds

Water waste occurring in an oil refinery is pumped into one end of interconnecting lagoons where it undergoes biological oxidation. The waste contains a small percentage of oil which accumulates in the ponds. The heavier accumulated oil waste is removed from these ponds and trucked to oil waste areas. Phenols and other oil waste products are broken down by microorganisms which feed on these materials.

During the filtration from one pond to another, the oil water mixture is aerated to increase the biological action. Algae are attracted to the carbon dioxide generated by the bacteria, which completes the biological process.

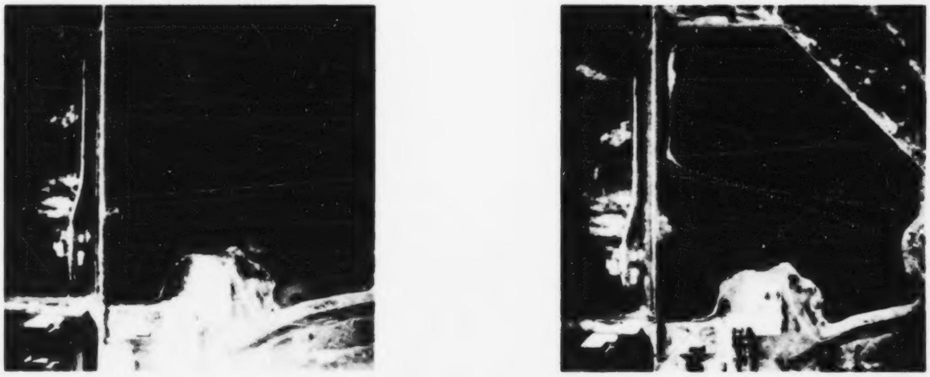
The oil detention pond area shown in Fig. 13 is part of a larger pond complex. The complete complex is on the river side of a levee. A flood control drain located north of these ponds reduces the potential threat of river contamination by these ponds during times of high water. The ponds themselves are enclosed by lesser dikes to ensure their separation. The dikes appear well maintained and have controlled flow from one pond to the next. The larger pond has an area of 6.8 acres but the depth is unknown.

Because ground truth teams had positively identified oil in water, extensive multiband flights were conducted over this area to determine the best film/filter combination for the detection of oil in water. These results are directly applicable to other areas for positively identifying an unknown spill or seepage into an inland waterway as oil.



a) Ground truth photograph

b) 2448/HF3



c) 2403/99

d) 2424/65

Figure 12 Power plant fly-ash pond

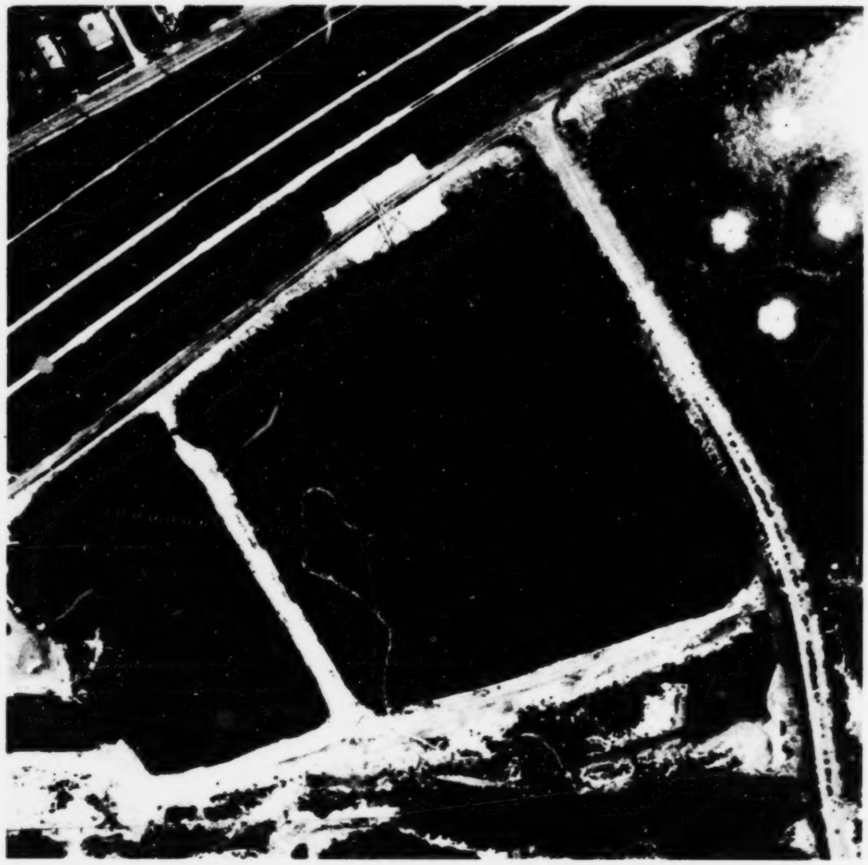
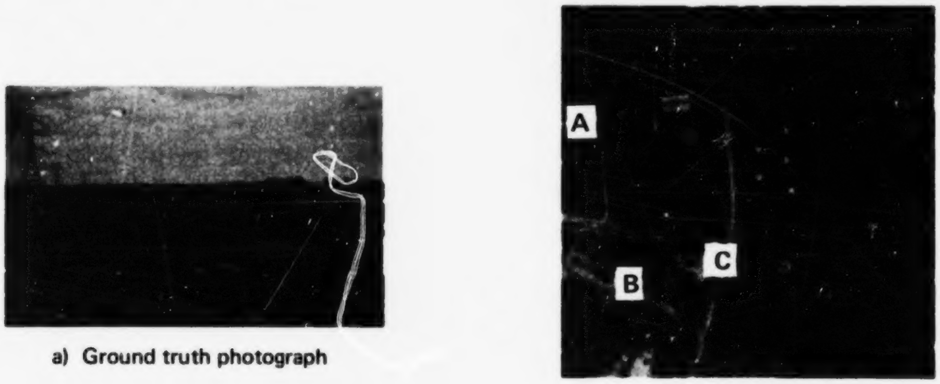


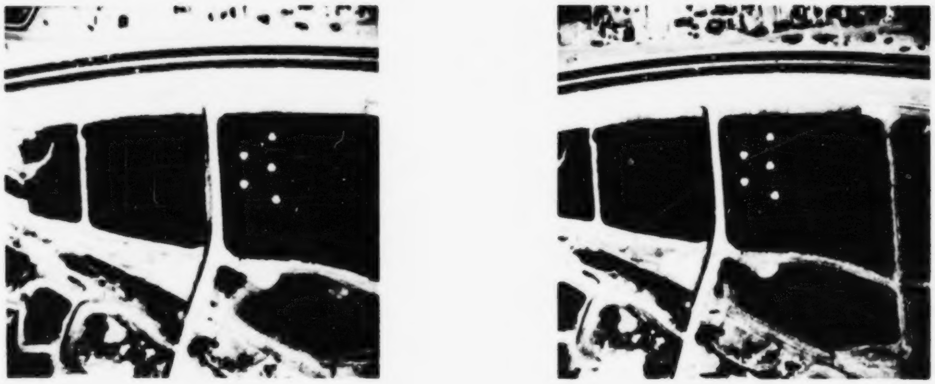
Figure 13 Baseline imagery of waste oxidation ponds

A ground truth photograph of the pond is shown in Fig. 14a. An aerial color photograph of this area covered during the multiband flights is shown in Fig. 14b. The five "starred" areas are the aerators. The oil waste initially pumped into the pond may be seen in the left-hand portion of the photograph labeled area A. The best film/filter combinations for identifying the oil in the ponds were found to be 2424/99, 2424/32, 2403/99, and 2403/35, as shown in Figs. 14c, 14d, 15a, and 15b, respectively. Similar results were obtained with filters 99 and 98 and with 32 and 35 with both film types 2403 and 2424. The maximum contrast of oil-water was obtained with film type 2403 because of the strong absorption of water in the near-infrared as recorded by film type 2424. Film type 2403 and filter 35 or 32 and 98 or 99 give the best oil-water contrast.



a) Ground truth photograph

b) 2448/HF3



c) 2424/99

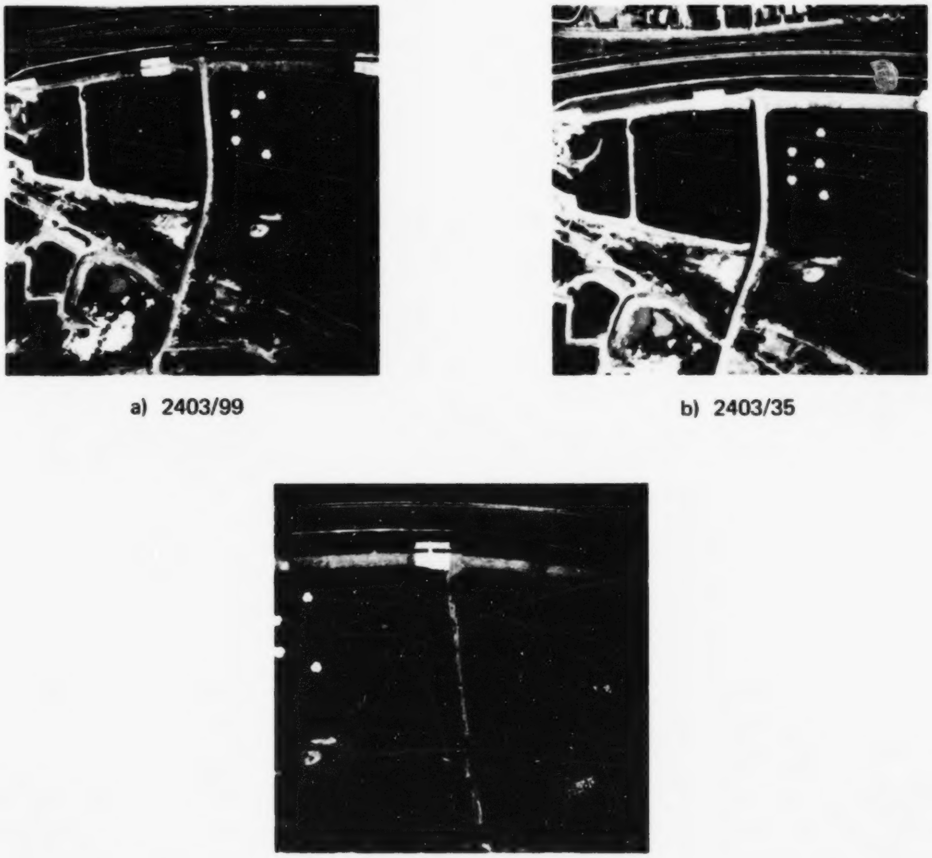
d) 2424/32

**Figure 14 Waste oxidation ponds**

In this pond area, a similar contrast enhancement for oil-water imagery is obtained with film/filter combinations 2403/99 and 2403/35. Since filter 35 transmits the ultraviolet, blue, and red radiation reflected from oil waste, the imagery obtained from 2403/99 was expected to be darker than that obtained with 2403/35. The similarity of these images indicates water absorption of this radiation.

An interesting result was observed in the area labeled C in Fig. 14b. In the infrared imagery recorded on film type 2424, area C appears dark while the pond to which it is connected is much lighter. On the film type 2403 imagery, however, area C has the same tonal quality as the rest of the pond. While this contrast enhancement is indicative of oil in the infrared imagery, none appears visible in the color photograph. It was further noted that the area C image density is the same as that of the pond containing the aerators. Ground truth revealed area C was much deeper than the rest of the pond to which it is connected. Thus, the darker pond area in the infrared imagery is a result of greater near-infrared absorption by the deeper water. Film/filter combinations 2424/32 or 2424/99 may have some value in determining water pond depths but the effectiveness and range of detectable depths is presently unknown. Thus, one has to be careful in interpreting pond imagery on film type 2424 so as not to mistake oil for water.

The imagery of this pond recorded with film/filter combination 2403/18A is shown in Fig. 15c. Filter 18A transmits the ultraviolet radiation of the spectrum (300 to 400 nm). With this filter, some water penetration can be seen since flow patterns from one pond to the next could be seen. Since oil is strongly reflective in this spectral region, the observed striations are believed to be oil.



a) 2403/99

b) 2403/35

c) 2403/18A

**Figure 15** Waste oxidation ponds

## Oil Refinery Effluent

The waste treatment ponds described in the last section eventually empty into the river and could represent a potential threat to the river. A baseline photograph of the effluent area is shown in Fig. 16. The drain, labeled A in the photograph, is approximately 28 ft wide and is controlled by a large gate valve. From this point it flows underground to the river. The river opening is approximately 15 ft wide and can be located by the plume of liquid being dumped into the river.

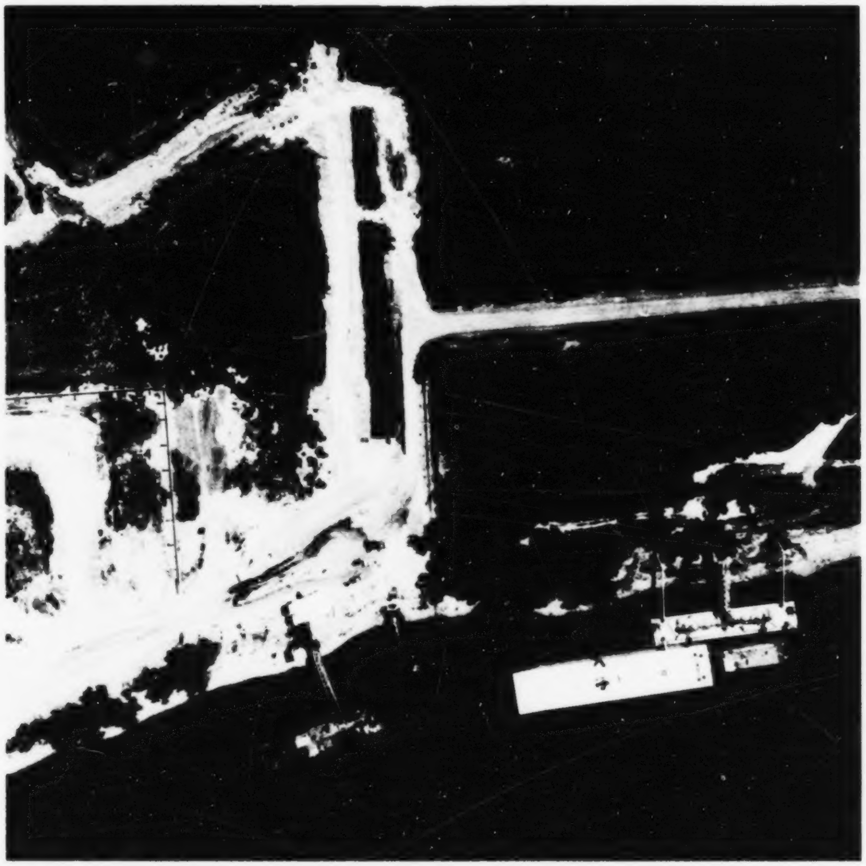


Figure 16 Baseline imagery of oil refinery effluent

An aerial color photograph containing the oil refinery effluent (labeled A) is shown in Fig. 17a. A ground truth photograph of this effluent is shown in Fig. 17b. Ground truth teams reported no visible evidence of oil at this effluent. The white caps seen in both Figs. 17a and 17b are an unusual feature of this effluent which the oil industry has been unable to remove. Fish are known to gather at this effluent to feed.

Multiband photographs were taken of this area to determine if previously successful film/filter combinations for oil in water detection would detect any presence of oil at this effluent. An examination of the multiband imagery revealed the effluent image density was approximately the same for all filters combined with both film types 2403 and 2424. This was expected as the white foam reflects all visible radiation uniformly. The white effluent recorded on film type 2424 had better contrast against the water background than that observed with film type 2403. This is a result of the near-infrared absorption of water recorded by film type 2424.

Filters 18A, 47B, and 39 transmit blue and ultraviolet radiation which penetrates water surfaces. As pointed out in the last section, images recorded with these filters and both film types 2403 and 2424 revealed oil flow patterns in the lagoon. Figure 17c is the imagery of the oil pond effluent as recorded by film/filter combination 2424/47B. The 47B filter does allow some water penetration as the white foam can be seen dissipating in the river.

While some contrast enhancement and water penetration are gained with multiband photography, no oil could be detected in the water. Color photography was concluded to be more effective for monitoring this type of effluent.

## Titanium Plant Effluent

Along the 1032 ft river front shown in Fig. 18, nine sources of water effluents are detectable and represent a real or actual threat to the inland water way. The pipes drain directly into the river with no visible evidence of plant control facilities. The materials being discharged appear the same on the baseline imagery. Ground truth of the area disclosed the following information:

Source A - Undissolved ore-gangue from clarification tanks, brownish black in color

Source B - Cooling basin overflow river water

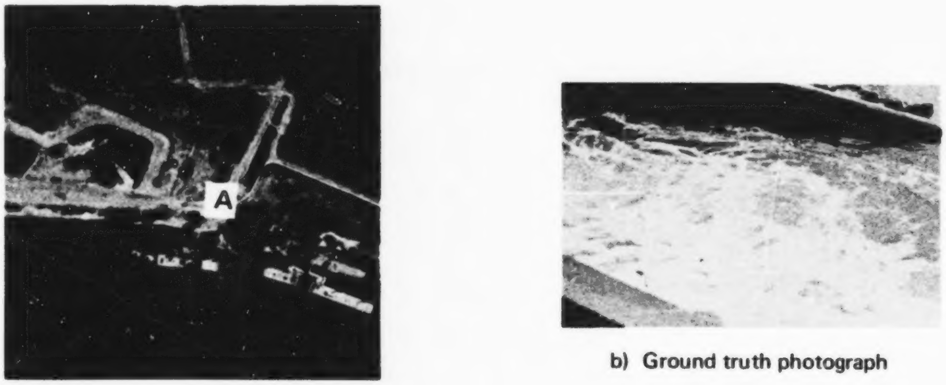
Source C - Cooling and processing water from ore digestors stack scrubbers not suited to recirculation

Source D - Process water which is orange in color

Source E - Process and runoff water from plant, three separate outlets

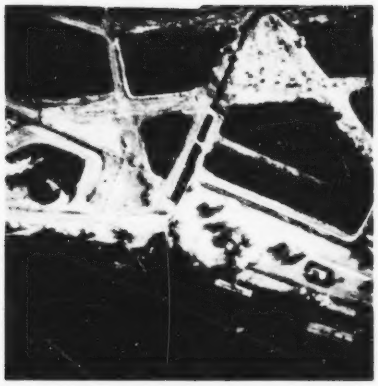
Source F - Main plant waste containing titanium dioxide, ferrous sulfate, and sulfuric acid

Source G - Cooling water from sulfuric acid manufacturing process



a) 2448/HF3

b) Ground truth photograph



c) 2424/47B

Figure 17 Oil refinery effluent

The tanks identified in Fig. 18 are intricate components of the manufacturing process and receive periodic inspection and the same maintenance as any other manufacturing machinery. The tanks are partially masked by associate structures, but appear unrevetted and would drain to the river if ruptured.

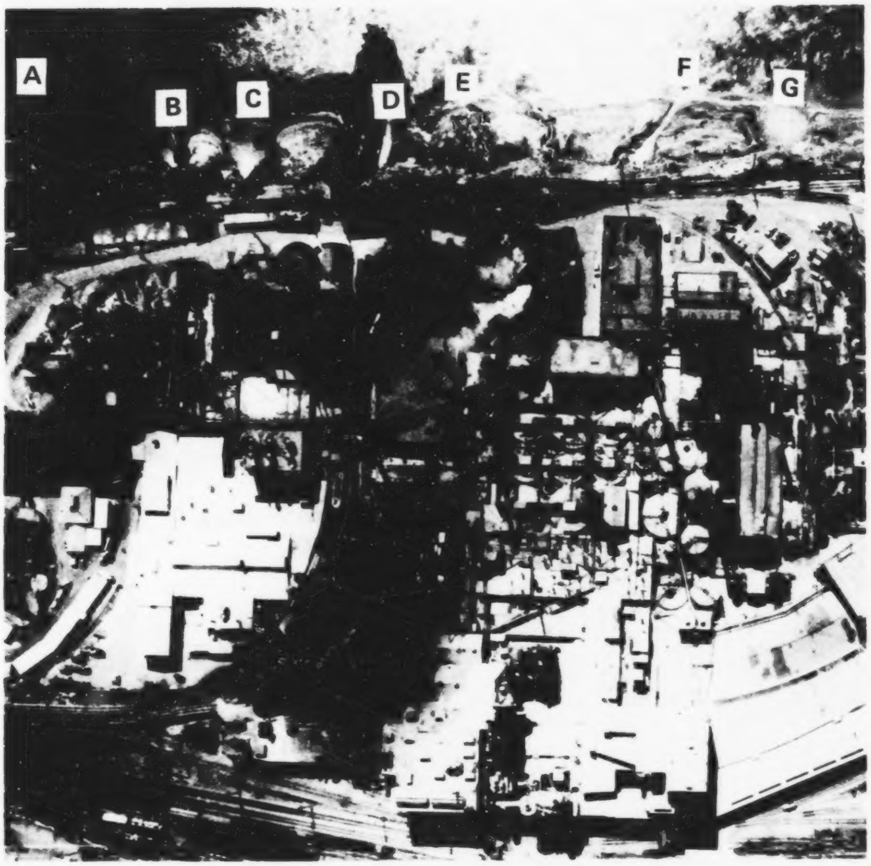


Figure 18 Baseline imagery of titanium plant effluents

Multiband photography was flown over the titanium plant effluents to determine if any film/filter combinations could be used effectively for identifying materials discharged into the river. Figure 19 is an aerial color photograph of the titanium plant and its effluents. The effluents on the 70-mm photographs are distinguishable to the unaided eye, but a 10X magnifier helps to identify each area. Effluent A is brownish black in color and consists of undissolved ore called ore-gangue. While no active effluent is evident, the stagnant water in this area on the 70-mm film displays a grayish color. During periods of low water the effluent is piped further down the bank and exited at the water intake tower. Effluent B primarily contains cooling water. On the color photograph the water appears similar to river water. Effluent C is also cooling and processing water. On the color photograph the effluent is lighter than the river and is probably due to aeration. Effluent D is processing water that contains iron sulfate from water treatment compounds from boiler water treatment and appears orange in Fig. 19. Effluent F, the main plant sewer, contains such wastes as titanium dioxides, ferrous sulfate and sulfuric acid. The exited material appears very gray. Effluent G is the raw river water used for cooling in the sulfuric acid manufacturing area and appears light gray.

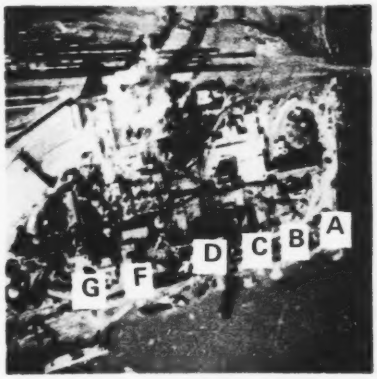


Figure 19 Titanium plant effluents

All of the multiband imagery of these effluents looked approximately the same. Therefore no one film/filter combination was effective in contrast enhancing any of the effluents. This is the result of the spectral characteristics of these effluents being either very broad or narrower than the spectral bands achieved with the film/filter combination. Overall, the color photography was very effective in determining the effluents and their general spectral signatures.

Figure 20 is a thermal infrared image of the titanium plant and its effluents. Most of the plant processing areas appear very bright, indicating a temperature increase over the background. Some of the effluents also appear bright and represent a warm or hot effluent. From the ground truth missions, process cooling water is known to be emptied into the river and could constitute an infrared return. For this type of industry, the value of infrared photography over multiband or color photography is in identifying various processing facilities by their temperature signature and in identifying real thermal pollution threats to the inland waterway.

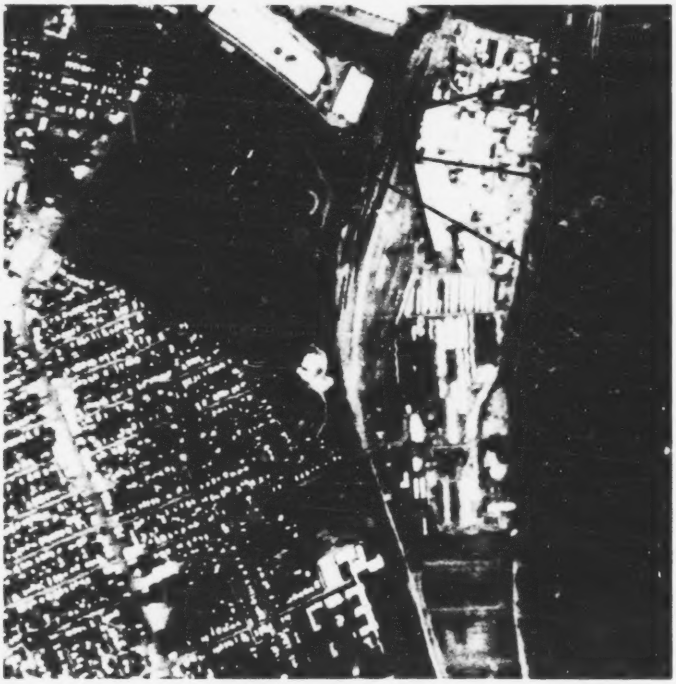


Figure 20 Thermal infrared image of titanium plant and effluents

## Sewage Effluent

In concurrence with the sites selected with the Environmental Protection Agency, a sewage effluent outlet was included in the baseline and multiband flights. This was not a primary target but demonstrates the photographic detection of a potential threat (if the sewage to water ratio is not in an acceptable range) and demonstrates the use of multiband photography to distinguish the presence of a variety of materials through their spectral characteristics.

The sewage discharge, confined between flood dikes to form a simple drainage pattern, is shown in Fig. 21. The drain is approximately 20 ft wide and dumps into a navigation canal 468 ft wide. The effluent from the sewage facility is very dark, indicating the presence of oil which could come from the various industries, including a steel mill, which drain directly into the sewage system. Figure 22 is an aerial color photograph of the sewage effluent. The best film/filter combination for detecting the effluent was found to be 2403/99, as shown in Fig. 22b. The use of this film/filter combination confirms the presence of a high percentage of oil. The film/filter combination suppresses the radiation reflected from oil and again emphasizes negative contrast enhancement. Figure 22c shows the imagery obtained with the film/filter combination 2424/99. The high absorption by water of near-infrared radiation reduces the sewage-water contrast drastically. When the imagery is compared with that obtained from the oil refinery, the observed contrast reduction is probably a result of near-infrared reflectance from materials

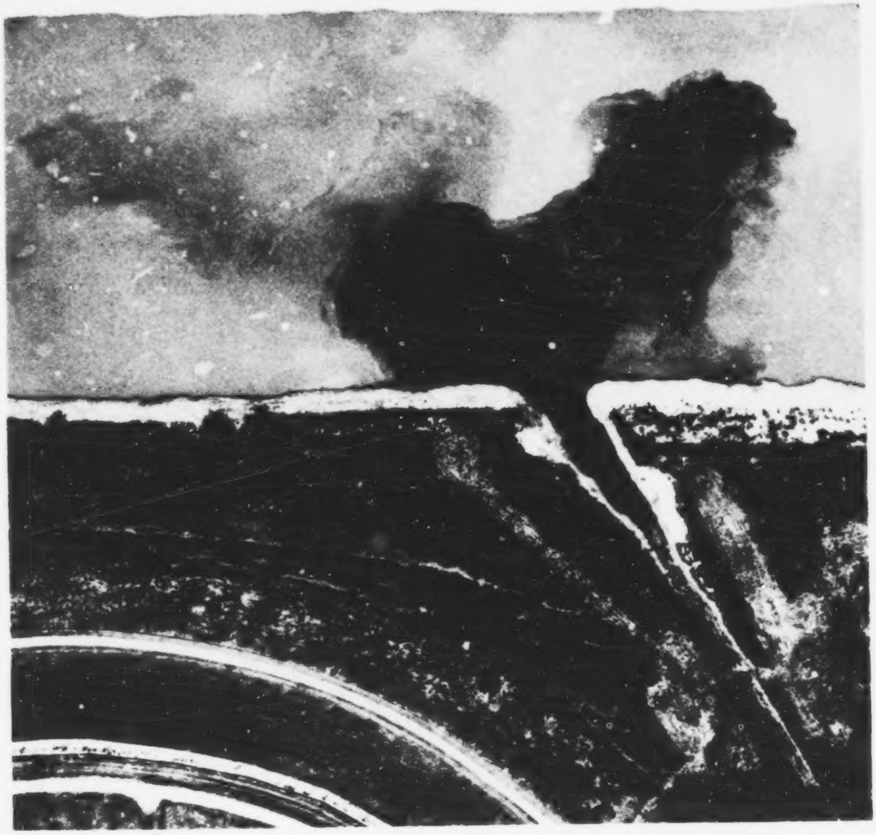
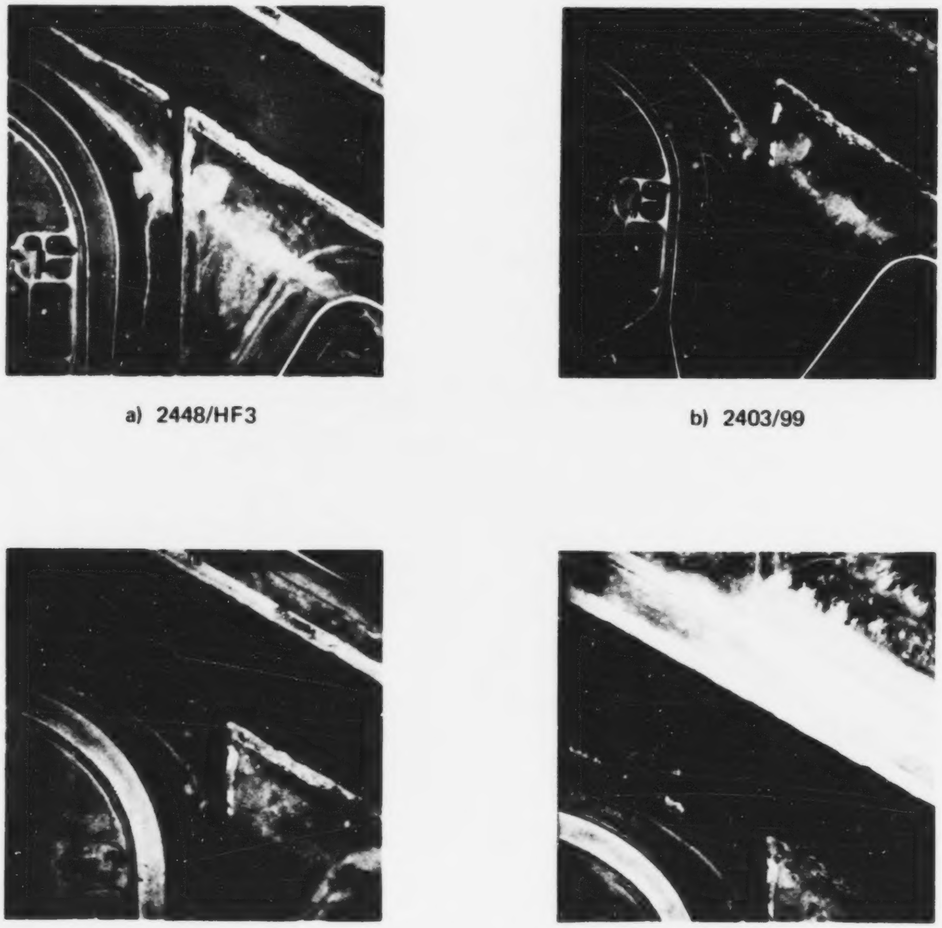


**Figure 21** Baseline imagery of sewage plant effluent

other than oil. The multiband imagery obtained with film/filter combination 2424/65 is shown in Fig. 22d. A contrast reversal of the effluent is observed in the imagery. The near-infrared absorption of the water provides a dark background for the lighter effluent. The use of filter 65 indicates a reflectance of the effluent in the 450 to 550 nm spectral region.



a) 2448/HF3

b) 2403/99

c) 2424/99

d) 2424/65

**Figure 22 Sewage plant effluent**

From a comparison of the imagery obtained with these three film/filter combinations, it can be concluded that other waste materials besides oil are present. The large number of industries dumping waste into the sewage system precluded identifying specific waste products.

## Power Plant Effluent

The power plant pumps water from the river into the main plant to be used for cooling. The heated water plus the plant sewage constitute the power plant effluent. Hence the threat to the inland waterway is thermal pollution. The liquid discharge area of a power plant is shown in Fig. 23. The primary discharge is through two cement structures approximately 13 ft by 26 ft and equipped with gates. A secondary discharge is located to the lower right of the cement structures and comes from a cement pipe approximately 2 ft in diameter. The discharge contains raw sewage and drainage from within the plant itself.

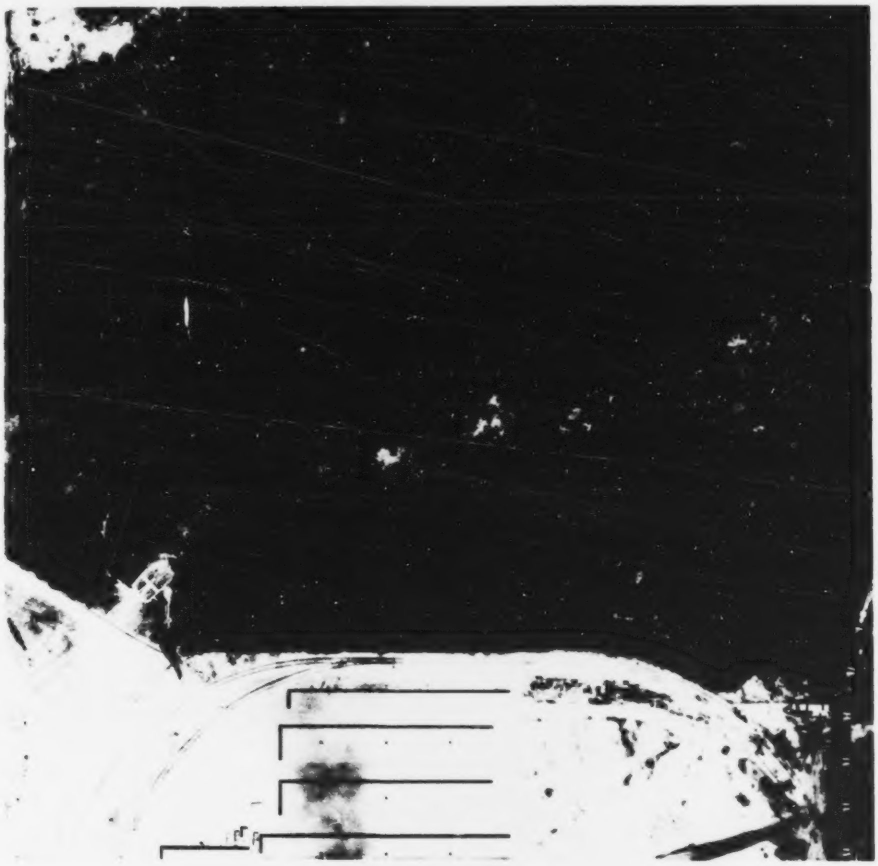


**Figure 23 Baseline imagery of power plant effluent**

A ground truth photograph of the power plant effluent, Fig. 24, shows that the spectral signature is not any different than that of the surrounding river water. Hence multiband photography is of no value in determining the type of material exited at this particular point. The presence of the effluent and its location relative to the river can be obtained from baseline photographs.

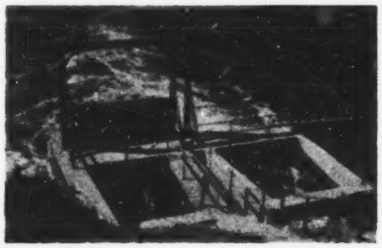


**Figure 24** Ground truth photograph of power plant effluent

As the water exited at the power plant has a higher temperature than the surrounding river, thermal infrared imagery should be effective in defining this effluent. Figure 25 is a termal infrared image of the effluent obtained from the Reconnaissance Laboratory Data base in which the heated effluent does appear lighter than the river background. Therefore, thermal infrared imagery is very effective in locating and tracing a heated effluent that cannot be detected by multiband or color photography.

### Lime Sludge and Oil Waste Area

One non-oil waste material that may be found in abundance in an oil refinery is lime sludge which is derived from the water softening processes employed. Generally, the lime sludge is trucked or pumped to a land waste area for natural absorption and decomposition.

Much of the oil waste encountered from tank storage in the oil industry is deposited in waste ponds. These differ from lagoons in that they are stagnant and are not filtered and discharged into the river. Natural biological action is the process used to break down the oil waste.

The large dump area shown in Fig. 26 is used for the disposal of lime sludge and oil waste. The area is located 2.8 miles from the river and does not represent a direct threat to the inland waterway. The non-river location was covered in the baseline and multiband photography to demonstrate the ability to establish drainage patterns and to positively identify lime sludge. These results can then be applied to evaluate real and potential threats of similar sites located adjacent to inland waterways.

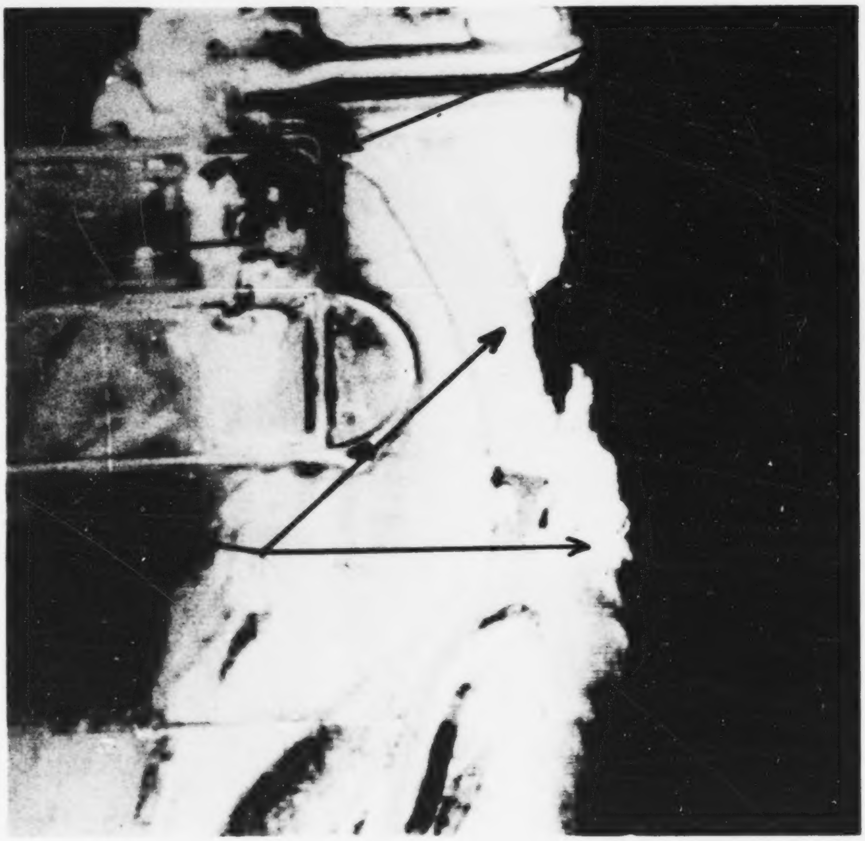


Figure 25 Thermal infrared image of power plant effluent

The pit shown in Fig. 26 measures approximately 1018 ft at its longest dimension and is 544 ft wide. The waste, by area, is approximately one-third liquid. The area in the photograph slopes from right to left and forms one portion of the low hills which surround this general area. The waste is dumped into the upper right-hand corner of the pit and runs to the lower left, as is evident by the drainage pattern. A dike, 18 ft above ground level, is located to the left of the lime sludge dump area.

Although no seepage is observed on the imagery, a drain pipe can be seen extending through the dike in the lower left-hand portion of the waste area. Drainage terminates into a swampy area located to the left of the lime sludge area.

The value of the multiband photography is the positive identification of lime sludge. Such results can be applied to identifying an unknown waste material to determine whether or not a waste area constitutes a real or potential threat to an inland waterway.

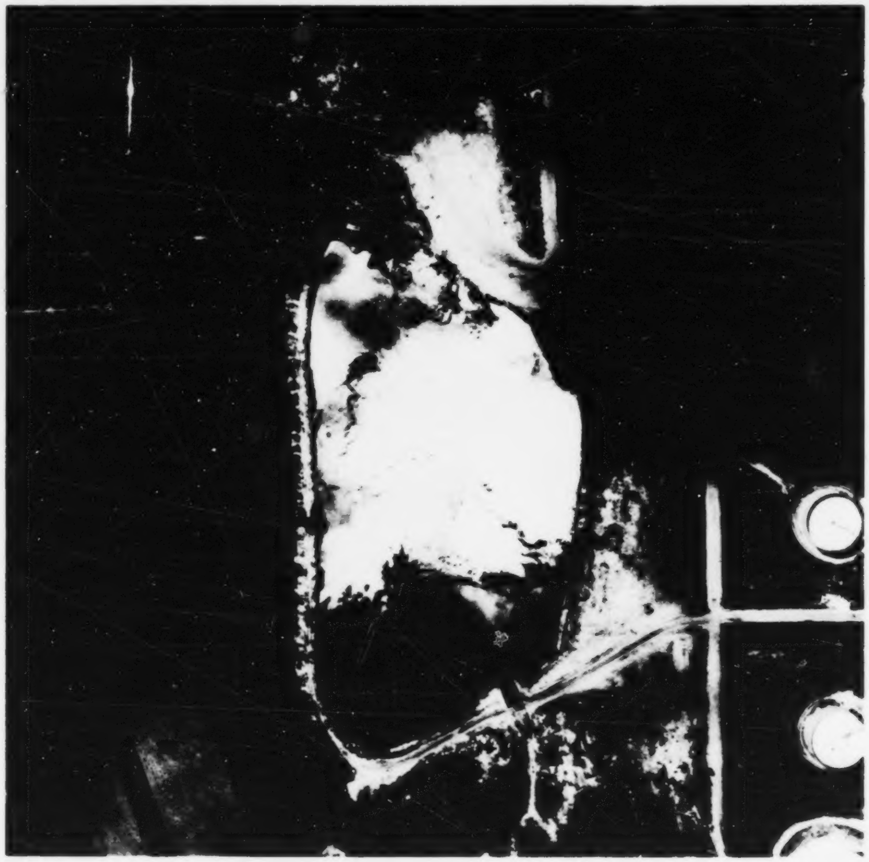
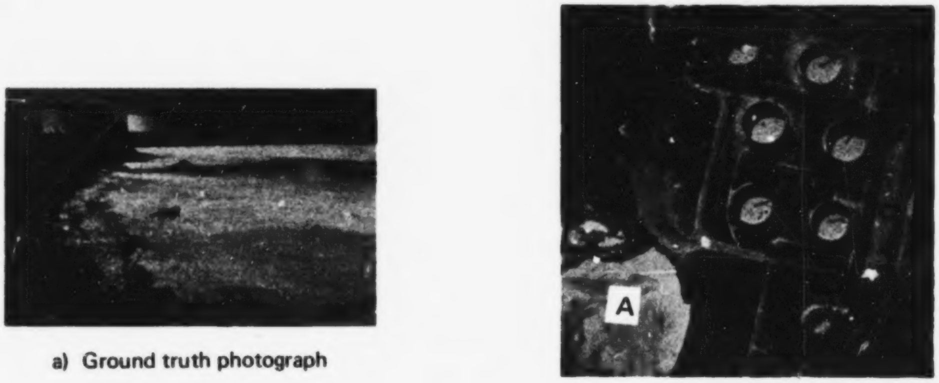


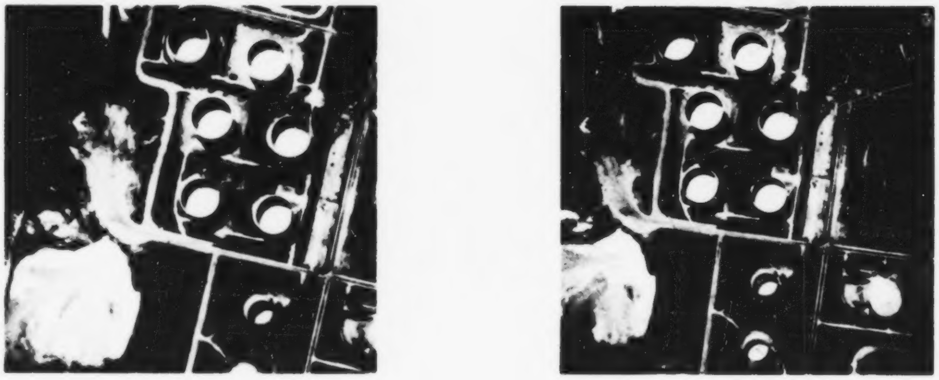
**Figure 26** Baseline imagery of oil refinery waste storage

Figure 27a is a ground truth photograph of the lime sludge area while Fig. 27b is an aerial color photograph of the same area covered during the multiband flights. The lime sludge area is labeled A in the latter photograph. The best film/filter combinations for identifying the area were 2403/65 and 2403/99. These images are shown in Figs. 27c and 27d, respectively. Filter 99 transmits the yellow portion of the spectrum (510 to 600 nm) while filter 65 transmission is centered around the blue-green spectral region (440-580 nm). Filters 98 and 75 yielded almost equivalent images with film type 2403 as the images included in this report. Filter 98 transmission is centered around 440 nm (390 to 500 nm) while filter 75 transmission is centered around 490 nm (450 to 540 nm). A good reflectance over the whole portion of the visible spectrum was expected because of the lime sludge's whitish color.



a) Ground truth photograph

b) 2448/HF3



c) 2403/65

d) 2403/99

**Figure 27** **Lime sludge waste area**

The imagery obtained with filter 65 appears to have slightly better contrast than that obtained with filter 99 due to the greater spectral bandwidth of filter 65. It should be pointed out that a positive contrast enhancement technique was used here. The image contrast has been optimized by choosing filters which transmit rather than suppress electromagnetic radiation reflected from the target of interest. Film type 2424 seemed of little use in this area as the near-infrared reflectance of the background reduced the contrast of the lime sludge area. In general, the multiband imagery defines the drainage patterns better than color photography. However, this gain is so slight that color photography appears to be the most effective detector of lime sludge areas and the drainage patterns that occur within these areas.

## Oil Waste Dump Area

The area below the pipeline, located at A in Fig. 28, is a portion of the waste disposal facility for a large oil refinery. The waste area shown is approximately 1550 ft long and 1008 ft wide at the widest point and is located between the flood levee and the river. The area is essentially flat with a major revetment surrounding the whole area to prevent any drainage into the river. In addition, each liquid pond is revetted and solid waste is dumped in a random manner further breaking up any permanent drainage pattern. Even though this area is located south of a control dam, a large flood would make the whole area a potential threat to the inland waterway.

Multiband photography was taken to determine the best film/filter combination for identifying and detecting the various dumped waste materials. These results can be applied to the detection and identification of unknown accumulated waste materials to determine if such material is a real or potential threat to the inland waterways. An aerial color photograph of this oil waste area is shown in Fig. 29a. Each area has been labeled in Fig. 29a, and they will be sequentially discussed. The best multiband imagery was obtained with film/filter combinations 2403/99, 2403/35, 2424/99, and 2424/35, and is shown in Figs. 29b, 29c, 29d, and 29e, respectively.

The area labeled A in the aerial color photograph is primarily a heavy oil waste area that has a very black appearance. The imagery obtained with filter 99 for both film types 2403 and 2424 is darker than that obtained with filter 35. As before, the contrast enhancement is a negative process based on the use of filter 99 to suppress the ultraviolet, blue, and red electromagnetic radiation reflected from the oil. Consequently, imagery obtained with filter 35 has less contrast as it transmits the portion of the spectrum reflected by oil. Also, the background of the imagery recorded on film type 2424 is lighter than that recorded on film type 2403. This is a result of near-infrared background reflected radiation and the extended spectral range of film type 2424. The oil waste area recorded on film type 2424 shows an increased relative contrast over that recorded on film type 2403.

The oil waste area labeled B in the aerial color photograph will now be discussed. On both film types 2424 and 2403, the imagery obtained with filters 35 and 99 have approximately the same contrast. This indicates that the ultraviolet, blue, and red radiation reflected from this area is negligible. Note, however, that the imagery of area B recorded on film type 2424 is lighter than that recorded on film type 2403. It can be concluded that area B reflects strongly in the near-infrared. Note that these spectral characteristics are different than those of area A. From these multiband photographs, the various waste materials can be separated and identified. From a ground truth mission it was learned that

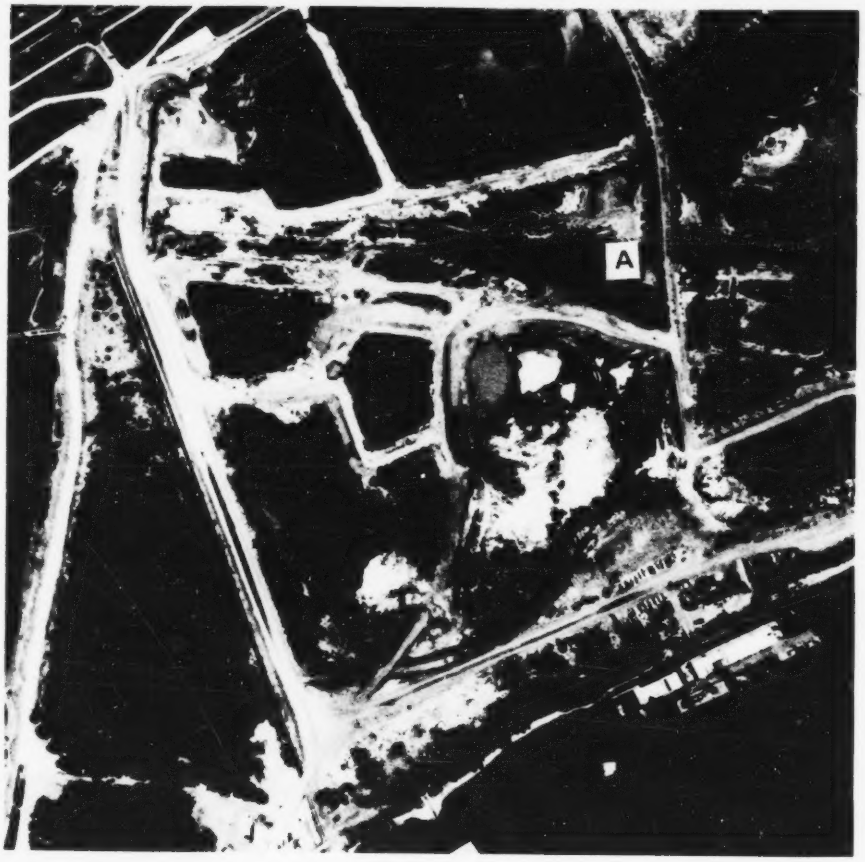


Figure 28 Baseline imagery of oil refinery waste area

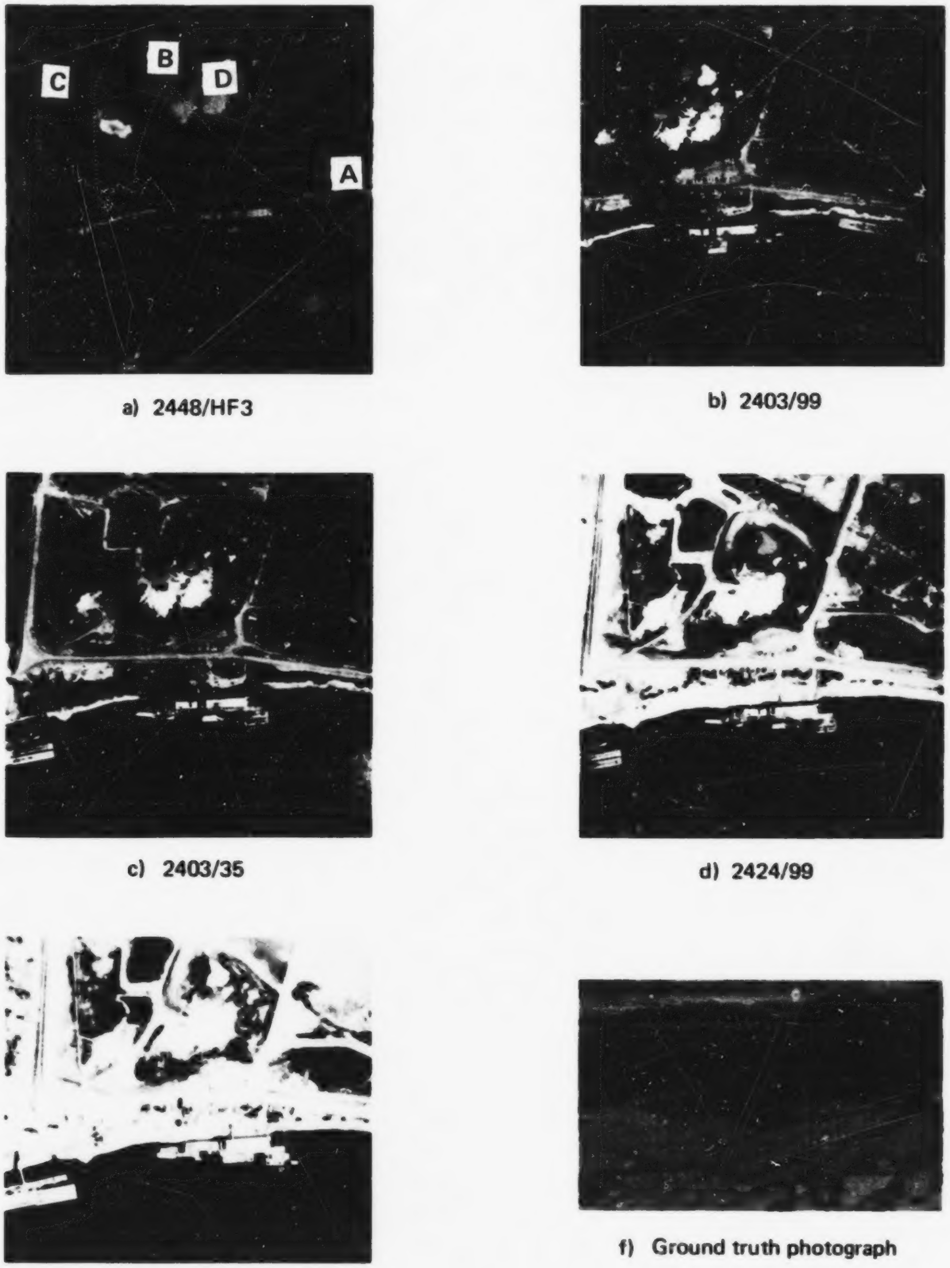
area C in Fig. 29a is an eight-year-old waste area containing oil-coated lime sludge. The brownish red color here indicates the pressure of filter cakes. A filter cake is diatomaceous earth used for filtering of certain motor oil additives in the processing plant. Upon saturation, it is flushed with oil to remove the motor oil additives. It acquires a blackish appearance and is dumped in an oil waste area. When the filter cake is rained on, the oil is leeched out in a reddish brown residue seen in area C. A ground truth photograph of a filter cake and oil residue is shown in Fig. 29f.

The multiband image of area C recorded with film/filter combination 2403/99 is very dark compared to that recorded by 2403/35. Some detail of drainage is apparent in the latter image. The results also support the reflectance of the ultraviolet, blue, and red radiation from the waste area. An examination of Figs. 29e and 29f of the imagery recorded with film/filter combinations 2424/99 and 2424/35 further supports this conclusion. The image of this area recorded with film type 2424 is lighter than that recorded with film type 2403, indicating a strong near-infrared reflectance. Area C is similar to area B except that there is some ultraviolet, blue, and red reflectance from this area.

Area D on Fig. 29a is the green and orange ponds that are very apparent in the aerial color photograph. The green pond is a result of algae that have formed on the oil waste product. The orange pond is an emulsified oil-water area. The green pond imagery recorded with film/filter combination 2403/99 is lighter than that recorded on 2403-35. This can be anticipated as filter 99 transmits the yellow-green radiation while filter 35 absorbs this radiation. The algae pond imagery has approximately the same tone when recorded with both film/filter combinations 2424/35 and 2424/99. The images are slightly lighter than that recorded on 2403/35, indicating some near-infrared reflectance.

The orange region recorded with film/filter combinations 2403/99 and 2403/35 appears to have the same image density. This is expected as both filters absorb in the orange spectral region. The imagery of the orange area recorded with film/filter combinations 2424/99 and 2424/35 appears to have the same contrast relative to the background. The area appears slightly darker on film type 2424 than on film type 2403, indicating some near-infrared absorption. In general, the multiband images of the orange and green ponds tends to be somewhat confusing and more is gained from the image recorded on color film type 2448.

Another oil waste area not located on the inland waterway is discussed in Appendix D. The area is interesting from the multiband photographic point of view because the oil waste is dispersed among stagnant water ponds, vegetation, filter cakes and emulsified oil waste. The conclusion for this area is that film type 2403 is better for identifying oil waste than film type 2424.



a) 2448/HF3

b) 2403/99

c) 2403/35

d) 2424/99

e) 2424/35

f) Ground truth photograph

**Figure 29** Oil waste area

GP71-1642-35

## Titanium Plant Open Storage of Raw Materials

In many industrial areas it is necessary to store large volumes of raw materials on the ground A portion of the storage facilities for a titanium plant are shown in Fig. 30. From the black-and-white photograph, the material identification is unreliable. A sulfur pile, labeled A in Fig. 30, was identified on an initial ground truth mission. It has a base of approximately 60 x 290 ft and is partially enclosed by a wall 4.5 ft high with access at either end for loading. The sulfur is stacked 10 ft above the wall. Since the entire area is protected by a levee, located at the top of the photograph, the river is not threatened by any runoff. If the levee were not present, however, natural drainage from such a source located within a 100 yds of the river would constitute a threat to the river. Additional items in the storage area labeled B, C, and D are a reserve coal pile, scrap metal, and fuel oil tank, respectively. The latter is enclosed by a protective dike, and a small fuel oil spill is observed at the base of the tank. The top of the tank appears to be stained from a previous overflow.

Multiband photography was taken of this area to determine the best film/filter combination for sulfur detection and identification. The results could then be applied to areas adjacent to an inland waterway to detect and positively identify an unknown spill to determine if a real or potential threat to the waterway exists.

A color aerial photograph of the area including the sulfur pile labeled A is shown in Fig. 31. An examination of the multiband imagery revealed that the similar contrast enhancement of the sulfur pile was achieved with filters 98, 99, 65, and 75 with both film types 2403 and 2424. Better contrast of the sulfur pile to the background was achieved with film type 2403 since the detection of background reflected near-infrared radiation by film type 2424 reduced the overall image contrast. Slightly better contrast enhancement was achieved with filter 99 as its maximum transmittance was in the yellow portion of the spectrum. Even with multiband image enhancement, the detection of sulfur was optimized with color photography.

## Coal Storage

The commercial coal storage yard shown in Fig. 32 is located at the intersection of two rivers. The coal pile is approximately 780 ft long and 535 ft wide and can be serviced by barge, rail, or truck. The storage is open without any protective dikes and apparently has no underground drainage system. A natural runoff pattern exists to the Mississippi River and to the river located at the right side of the photograph. Coal dust in suspension can be detected in the river down stream from the barge handling facility. Coal sediments can be seen in the creek just below the railroad bridge in the lower right of the photograph.

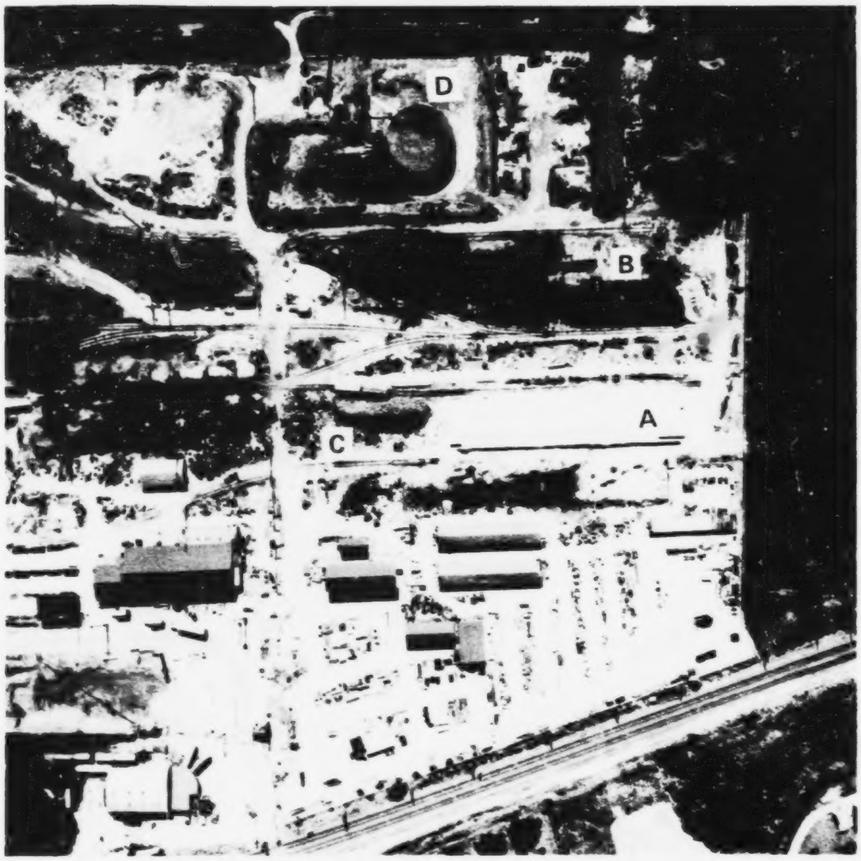


Figure 30 Baseline imagery of open sulfur storage

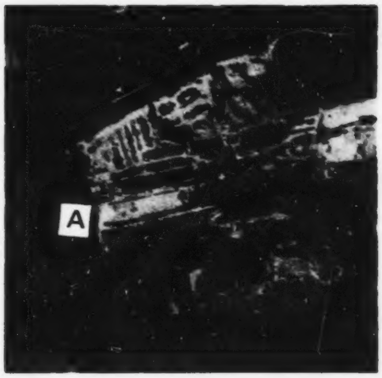


Figure 31 Sulfur storage area

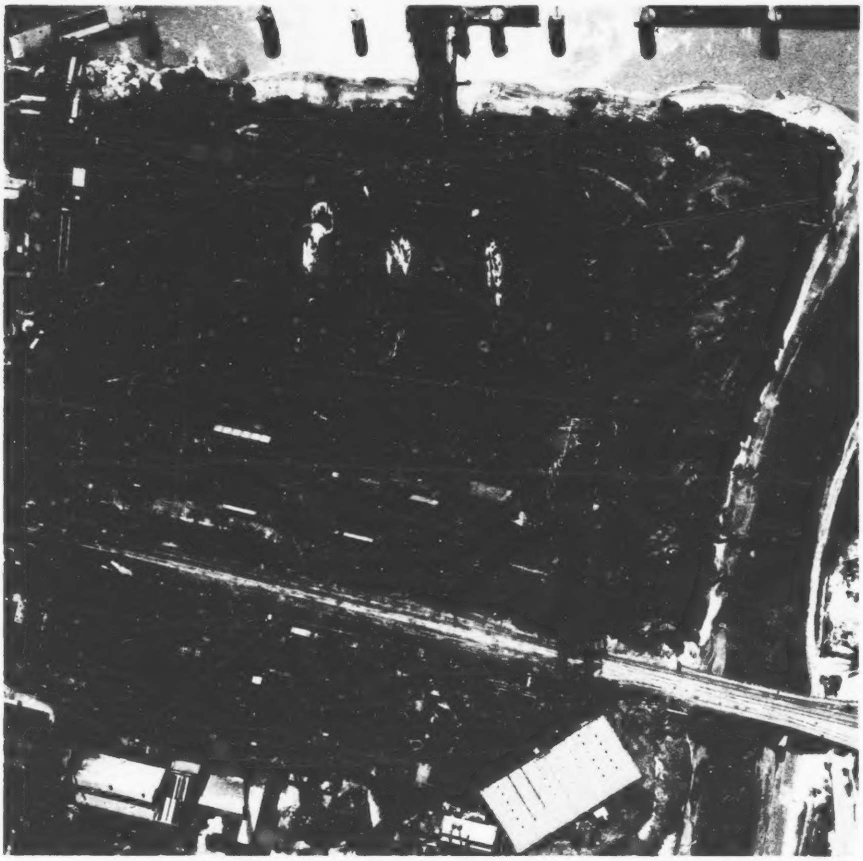


Figure 32 Baseline imagery of open storage of coal

A color aerial photograph of the area is shown in Fig. 33. A close examination of the area with a 10X magnifier revealed coal dust drainage from the coal pile into the river. Likewise, coal spilled in the river during barge loading can also be seen. The multiband imagery was examined to see if contrast enhancement of coal and coal dust drainage was achieved with any film/filter combination. Some contrast enhancement was obtained with filters 99, 98, and 75 with both film types 2403 and 2424. The contrast enhancement was obtained by suppression of the reflected radiation from coal which occurs in the ultraviolet and blue portions of the spectrum. After a detailed analysis was made of the multiband imagery, it was concluded that more information was available in the color photography. Making the coal pile darker in the multiband imagery does not particularly aid the photointerpreter.

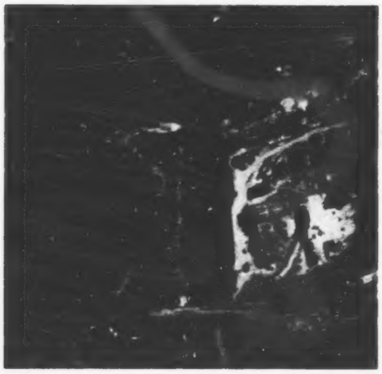


Figure 33 Coal storage and loading area

## Cement Plant Shale Quarry

In accordance with the sites selected with the Environmental Protection Agency, a cement manufacturing plant was covered in the baseline and multiband flights. The most interesting feature of this facility was the plant shale and limestone quarry. Fig. 34 is a baseline photograph of this quarry. It measures approximately 1000 ft at its longest point and 600 ft at the widest point. The pit is being worked at one end where the mechanical shovel and bulldozer are located. The material is transported to the opposite side of the pit by truck where it is dumped into a hopper. From there it is moved to the plant by an underground conveyer belt. A power drill on the upper level of the active area above the large shovel is used to bore shot holes for dynamiting.

Upon stereoscopic analysis, the quarry, located adjacent to the river, was found to have no natural drainage. Hence the area does not represent a direct threat to the inland waterway. All drainage collects in a pond located at the center of the quarry. The water is pumped from there to the main plant, where it is combined with the river water used to cool the kiln, for disposal into the adjacent river. Ground truth teams found no detectable waste material such as shale or limestone in the cement plant effluent.

The value of the multiband flights was in determining the best film/filter combination for detecting shale and limestone. The results can be used to locate and identify shale and limestone in other areas adjacent to inland waterways to determine if a potential threat to aquatic life exists.

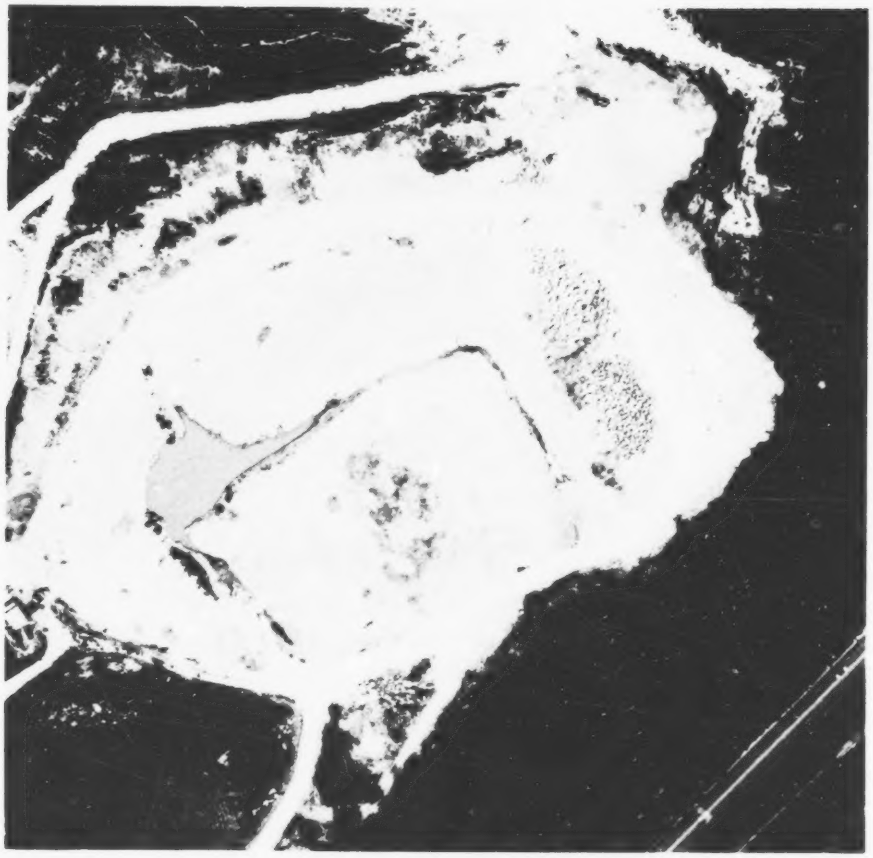
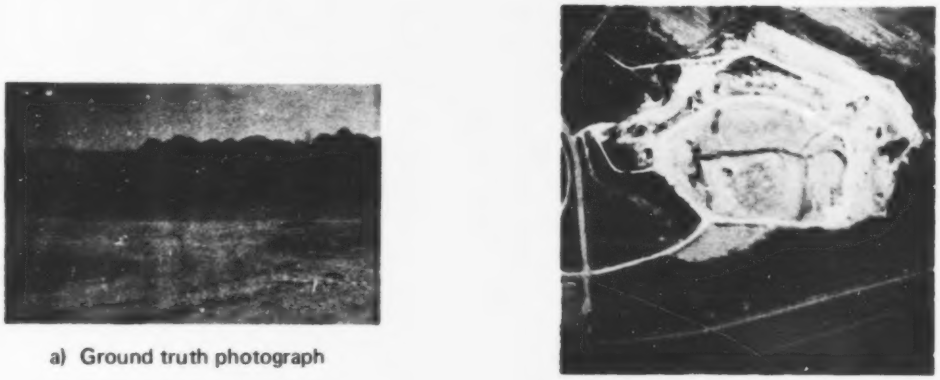


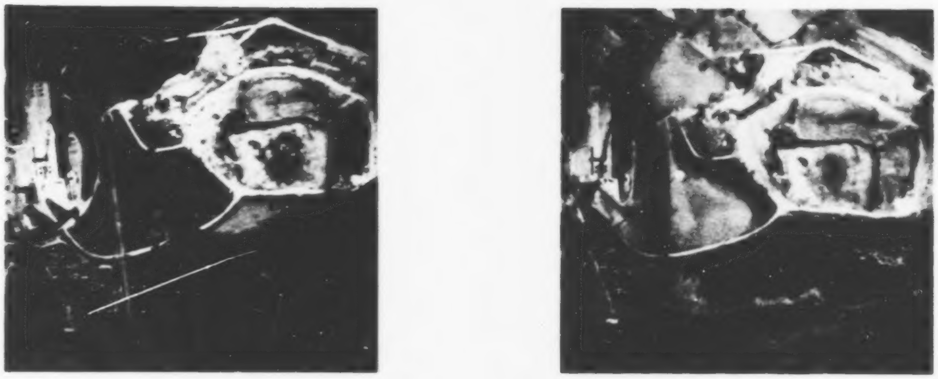
Figure 34 Baseline imagery of open shale quarry

A ground truth photograph and an aerial color photograph of the quarry are shown in Figs. 35a and 35b, respectively. From the photographs, the shale and limestone is observed to be grayish white. The multiband imagery analysis revealed the best film/filter combinations were 2403/99, 2403/98, 2403/75, 2424/99, 2424/98, and 2424/75. The imagery recorded on both film types 2403 and 2424 with filters 99, 98, and 75 appeared very similar. Figures 35c and 35d are the imagery of the shale and limestone



a) Ground truth photograph

b) 2448/HF3



c) 2403/99

d) 2424/99

**Figure 35 Shale quarry**

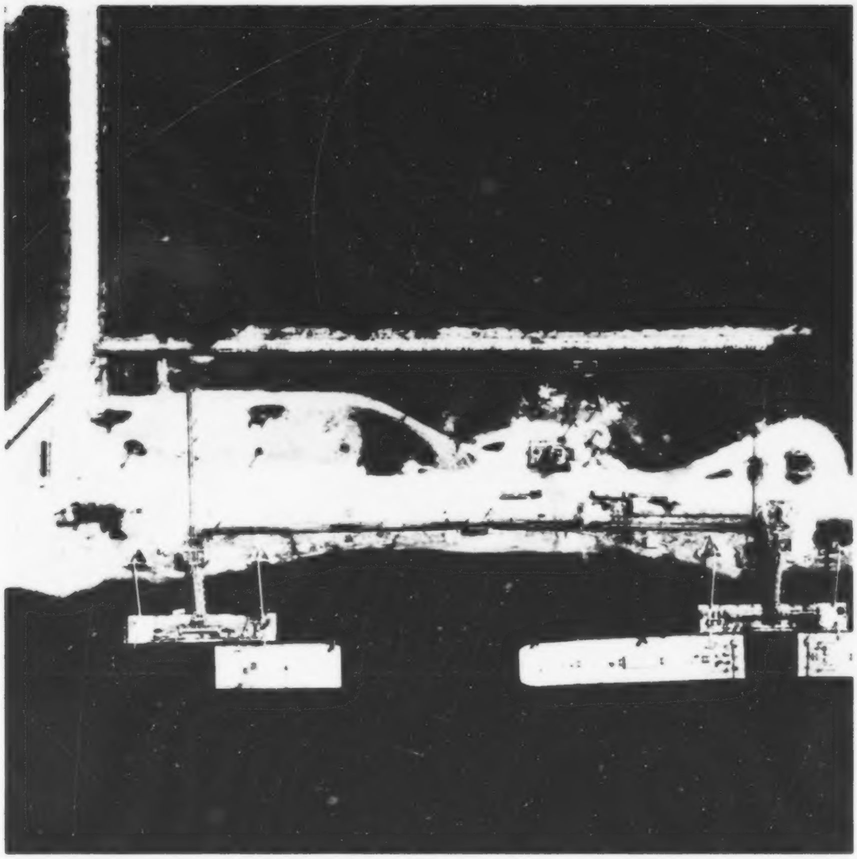
quarry obtained with film/filter combinations 2403/99 and 2424/99 respectively. All of the 2403 imagery gave better contrast of the shale quarry to the background reflected near-infrared radiation recorded by film type 2424. The wide range of acceptable filters is understandable as the quarry reflects visible radiation uniformly. For this particular area, color photography yields the maximum amount of information.

## Pipelines Over or Near Waterways

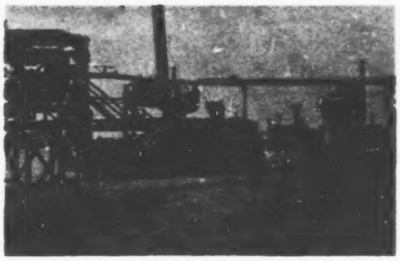
Figures 36a and 36b are the baseline and ground truth photographs, respectively, of a portion of the pipeline facility of a barge transfer system used by a major oil refinery. This portion is connected to the main refinery by four above ground pipelines. All lines appear in good repair with no spillage visible. A small amount of spillage is evident around a tank truck transfer point. The river transfer points are two floating docks connected to the shore and equipped with overhead pipelines. These floating docks could be a potential spill threat if a line were unattended during the actual transfer operations. One small open pit is located at the facility and shows signs of petroleum dumping. The drainage, however, does not reach the river. Generally, the overall appearance of this transfer area indicates good maintenance.

The petroleum transfer point shown in the base and ground truth photographs of Figs. 37a and 37b, respectively, is very similar to the transfer area discussed above. The facility is connected to the main plant by five pipelines and has pumping and flow regulation equipment on site. Two revetted tanks on the shoreline were being improved at the time the baseline photography was taken. The actual loading is done from two floating docks moored to the shoreline and equipped with overhead pipelines. The danger of spill threat during the actual transfer operations also exists here. No spills are in evidence at the time of photography.

The value of multiband photography over areas containing pipelines over or adjacent to waterways is in detecting and identifying spills occurring from pipe leaks or during barge-loading operations. The two barge-loadings shown in Figs. 36 and 37 were covered during the multiband flights. During these flights, no pipe leaks or spills in the barge-loading operations were detected. Hence, experimental evidence was not available to assess the effectiveness of multiband imagery in this area. Samples of the multiband imagery of one of these barge-loading areas are shown in Fig. 29. Oil would be the most probable spill threat to occur in this area. From other sections of this report the best film/filter combinations for detecting this spill would be 2403/99, 2403/32, 2424/99, and 2424/32. Film type 2403 would be more effective over the harbor while film type 2424 would be better over land areas. This result is based on the near-infrared absorption of water that reduces the oil-water contrast on film type 2424 imagery and on the ground reflection of near-infrared radiation that enhances the oil-ground contrast in film type 2424 imagery.

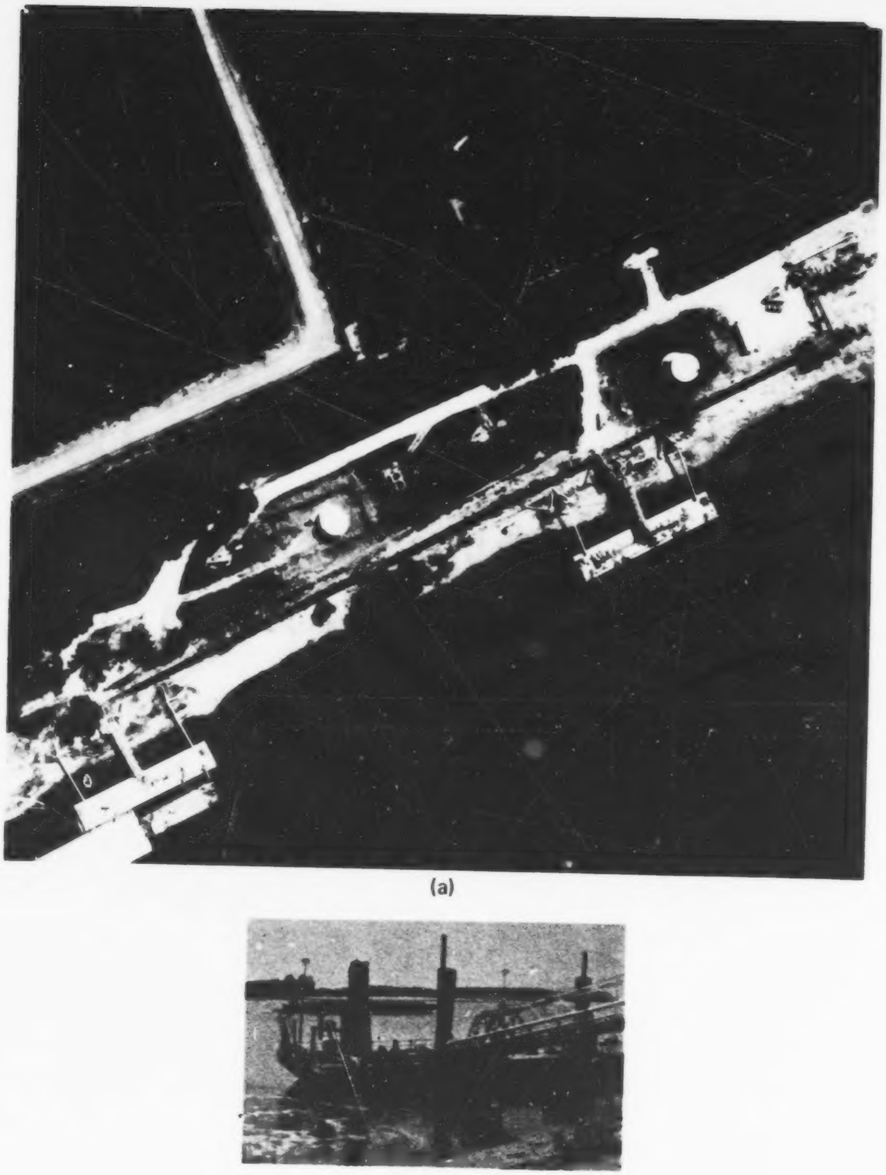


(a)



(b)

Figure 36 a) Baseline and b) ground truth imagery of barge loading area



(a)

(b)

Figure 37 a) Baseline and b) ground truth imagery of barge loading area

## Chemical Plant Loading Areas

In all the industrial areas covered during the flight plan, many examples of truck and rail loading were recorded. Loading areas having a natural drainage pattern to the waterway could represent a potential spill threat.

Figure 38 is a portion of a chemical loading facility covered during the flights. While the area is behind the flood levee, the analysis made here demonstrates the technique that can be used in similar areas located on an inland waterway. Areas A, B, C, and D are a sulfuric acid loading area, a sulfuric acid contact plant, cooling towers, and a reserve coal pile, respectively. The chemical storage area has one railroad siding equipped to load nine railroad tank cars sequentially and one truck facility capable of handling two tank trucks simultaneously. There are six large storage tanks, four smaller tanks, and two more large storage tanks under construction. The large and small tanks have a diameter of approximately 35 ft and 15 ft, respectively, and are approximately 20 ft high. From the black-and-white imagery, there are no apparent spill threats in the area. The area is very flat and would not represent a potential threat even if it were directly adjacent to the river. A very indistinct mottled appearance on the ground is attributed to natural soil difference.

Generally, the number of spills detected in all the industrial loading areas was very small. One example of a possible spill in the chemical plant is labeled A in Fig. 39a. A ground truth team learned the yellow residue on the ground at the sulfuric acid loading area is a result of storage of bulk sulfur in past years. Multiband photography was evaluated to determine if any film/filter combination was effective in identifying the sulfur deposits. The results could be used in areas adjacent to waterways to identify an unknown deposit to determine if it represented a real or potential threat to the waterway. An examination of the multiband imagery revealed that film/filter combinations 2403/99 and 2424/99 gave the maximum contrast enhancement. These images are shown in Figs. 39b and 39c, respectively.

Imagery obtained with filters 98 and 75 for both film types 2403 and 2424 gave the next best contrast enhancement of the deposit. It is reasonable to expect the maximum positive contrast enhancement with filter 99 as its peak transmission in the yellow portion of the spectrum. The amount of contrast enhancement is so slight that color photography is as effective in identifying and detecting this deposit as the multiband photography.

## Oil Refinery Loading Area

The photograph shown in Fig. 40 is a portion of an oil refinery having considerable loading facilities, tank storage, and administration buildings. The area is located 1.6 miles from the river behind a flood levee on a flood plain which has little or no natural drainage.

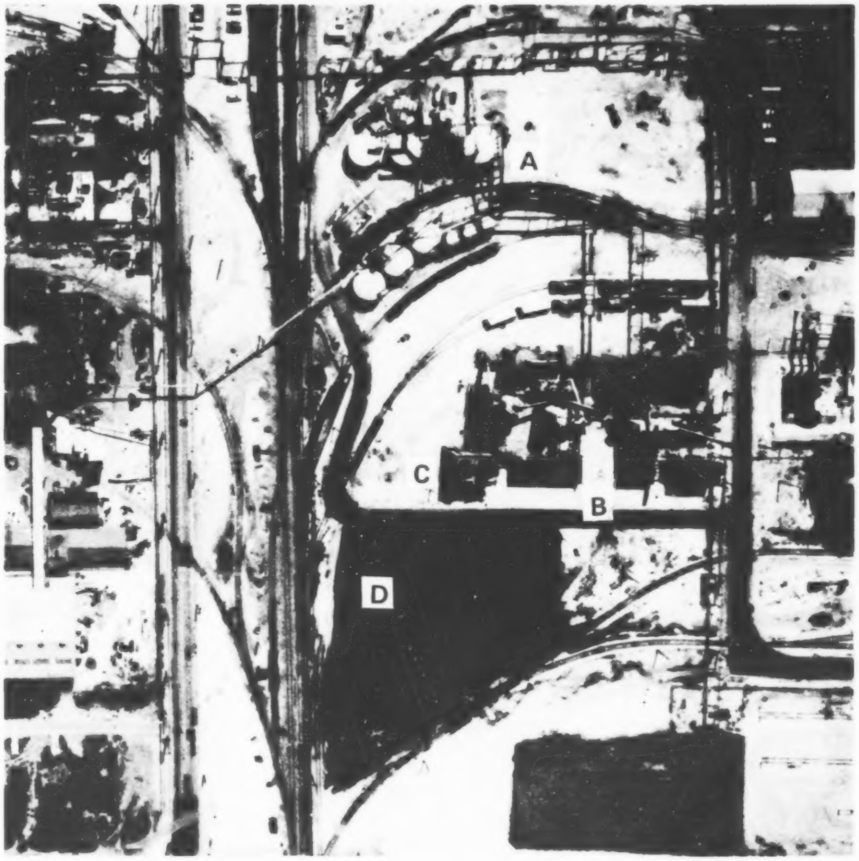
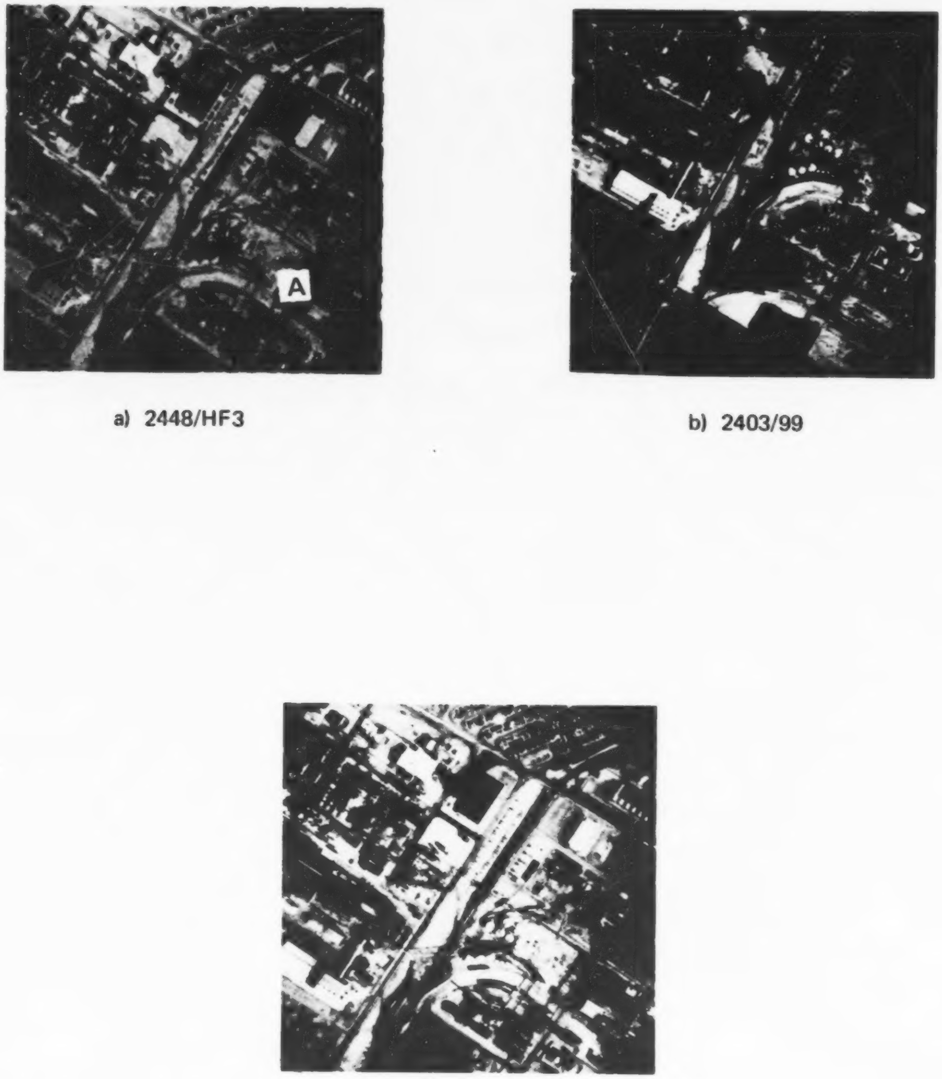


Figure 38 Baseline imagery of chemical plant acid loading area



a) 2448/HF3

b) 2403/99

c) 2424/99

Figure 39 Sulfuric acid loading area

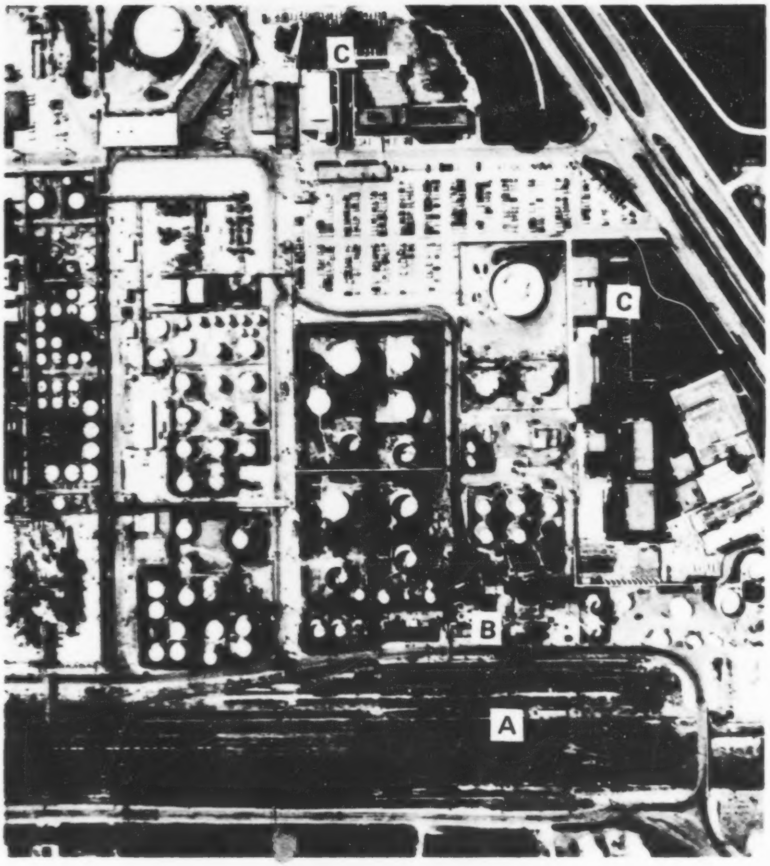


Figure 40 Baseline imagery of oil refinery loading area

The area in Fig. 40 does not have a ten foot difference in elevation between any two natural ground points. Any industrial complex located on such a flat terrian will require man-made controllable drainage for the removal of waste. Consequently the area does not represent a direct threat to the inland waterway. The analysis used here, however, can be applied to similar areas located adjacent to inland waterways.

The area marked A is for loading of railroad tank cars and contains five dead-end sidings. A maximum of 70 tank cars could be serviced from 35 double stations while 20 additional tanks cars could be serviced from the remaining single stations. The petroleum spillage is quite evident as an accumulation of very small spills rather than one large spill. Because the land is flat, there is no evidence of spills flowing out of the area requiring protective measures. Such a site located as an inland waterway would constitute a potential spill threat because of the large volume of petroleum products handled here.

The two areas marked B are for the loading of tank trucks. The area adjacent to A would probably handle four trucks simultaneously and shows some spillage accumulation which again is confined to this area. The area B closest to the main road will probably handle six trucks simultaneously and shows little evidence of spillage. This is probably due to the cement drive which drains to an underground sewer system. The areas marked C are administrative facilities while the building marked D is a warehouse.

Multiband imagery of an oil refinery loading area allows identifying spilled materials, and hence the spill source, by their spectral signature. Transferred materials in an oil refinery include final products such as gasoline, oil, and asphalt, and also waste materials such as lime sludge and crude oil waste. The best film/filter combinations to detect these materials have been discussed previously. Film/filter combinations 2403/99, 2403/32, 2424/99, 2424/32 have been effective in detecting oil and oil waste products through contrast enhancement on the multiband imagery. Similarly, film/filter combination 2403/65 is effective in contrast enhancing gasoline spills and lime sludge waste material. These film/filter combinations should be effective in detecting real and potential spill threats in an oil refinery loading area located adjacent to an inland waterway.

## Refineries and Industrial Processing Facilities

The industrial complex shown in Fig. 41 is the central area of a petroleum refinery where considerable processing and manufacturing is carried out. The area is of interest as the interconnecting pipeline and processing facilities can represent potential spill threats. Although this area is two miles from the river, the analysis used here can be applied to areas located adjacent to an inland waterway.

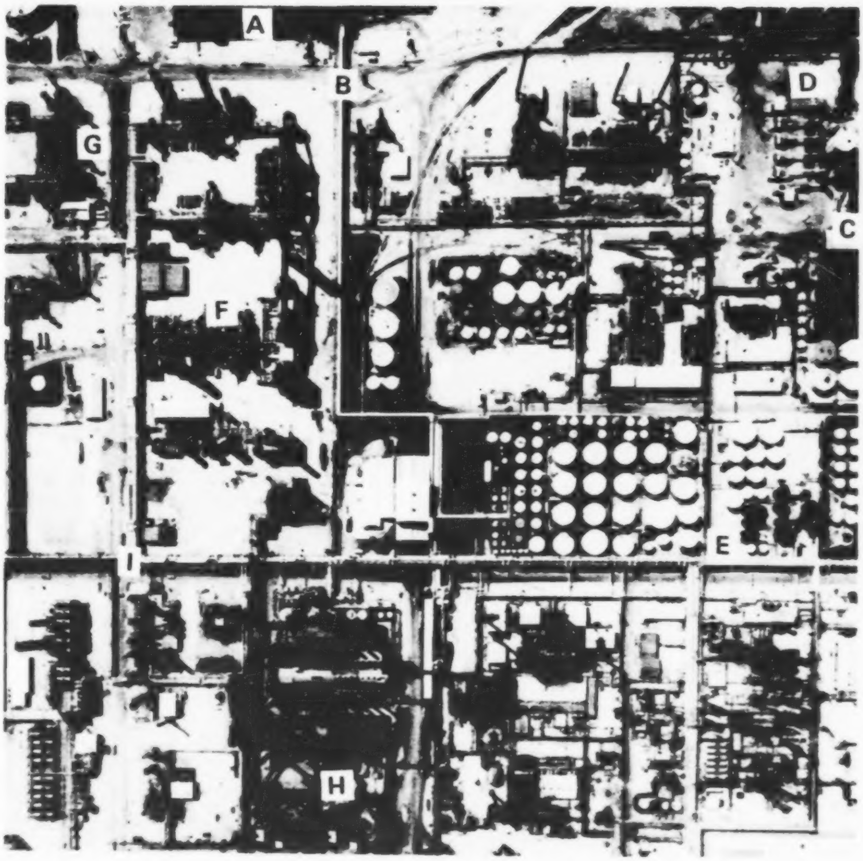


Figure 41 Baseline imagery of oil refinery

Although its complexity makes it a difficult area to analyze from aerial photographs, the following labeled areas are easily defined.

A - Product Warehouse - Storage with railroad car and truck loading facility

B - Overhead enclosed conveyer system

C - Railroad tank car loading facility

D - Tank truck loading facility

E - Liquid asphalt storage in dark tanks for heat absorbing quality

F - Cooling units with fans visible in top of units

G - Catalytic Reformer for the production of high octane aviation gasoline

H - Twin Catalytic Cracking Units for the refining of crude oil

I - Overhead pipeline complexes for the transfer of liquids within the plants

The tracing of individual pipelines through the complex is impossible. Although the amount of detail within the photograph is exceptional, the complexity of the operation is beyond determination from aerial photographs and no potential spill threats could be determined.

The value of multiband imagery from a refinery and processing area is for detecting and identifying pipeline and storage tank spills of oil and hazardous materials which could be potential threats to an inland waterway. Since no leaks from ruptured pipelines were observed during the multiband flights, no multiband imagery could be evaluated for this area. For an oil refinery, it can be deduced from previous sections that film/filter combinations 2403/99, 2403/32, 2424/99, 2424/32, and 2403/65 would be effective in enhancing spills. Over other industrial areas, however, color imagery was found to be more effective for detecting spills than any of the multiband imagery.

Figure 42 is a thermal infrared image of an oil refinery processing area that was obtained from the Reconnaissance Laboratory Data Base. The value of thermal infrared imagery of this type of area is in identifying storage tanks, pipelines, and processing facilities that contain recently processed materials that are warmer than their surroundings. From the imagery, pipelines containing temperature elevated materials can be traced to their respective storage facilities. Therefore, thermal infrared imagery can furnish information that cannot be obtained from color or multiband imagery. Such additional information can be of value in identifying particular industrial processes but sufficient information for locating and identifying real and potential spill threats can be obtained from baseline and multiband photography.

## Evaluation of Oblique Photography

An oblique photograph of an oil refinery complex shown in Fig. 43 is typical of this type of imagery. North is to the left of the photograph. Detail is greatly degraded by ground haze in the upper 1/3 of the photograph. To the layman, it is superior to vertical imagery because the viewer has definite clues regarding relative object heights. To the photointerpreter, however, the scale changes throughout the photograph, making mensuration difficult. The same area of the photograph, where detail is discernible, could be covered by a vertical photograph from a higher altitude. The scale of such a photograph would be constant throughout and contain more reliable vertical information when viewed stereoscopically.

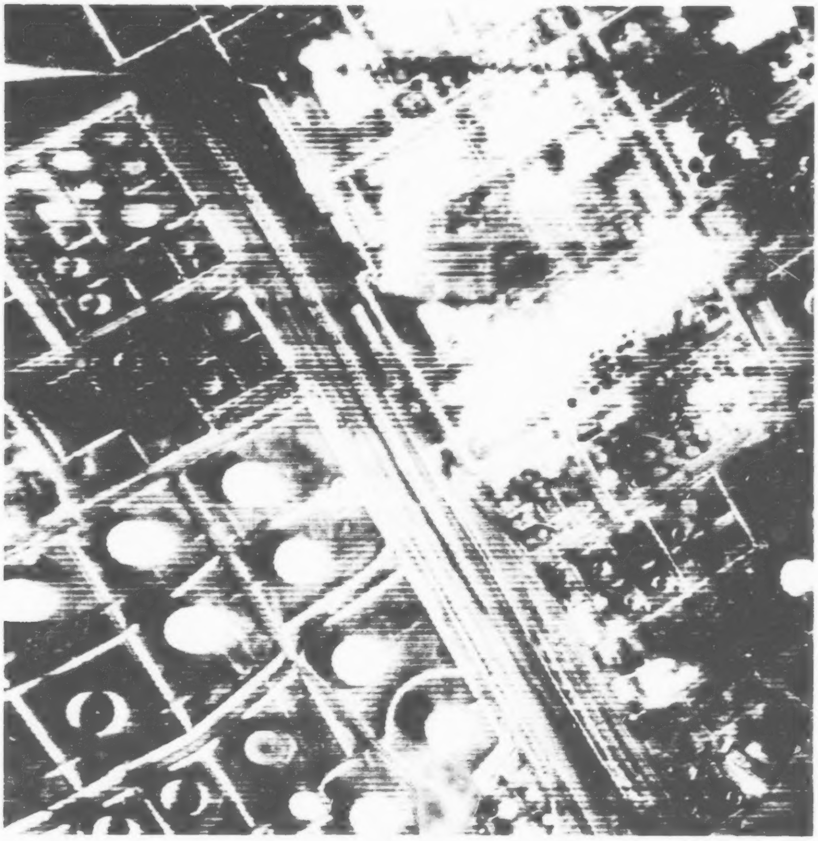


Figure 42 Thermal infrared image of oil refinery

## Effect of Weather Conditions on Imagery

During the flight test program, aerial imagery was taken only on clear or slightly hazy days to establish the maximum effectiveness of an aerial surveillance system. Haze and air pollution over the industrial areas, however, did affect the resulting imagery. Figure 44a is an aerial photograph of a chemical processing area obtained during conditions of haze and heavy air pollution. Figure 44b is an aerial photograph of the same area obtained on a clear day. Both of these images were recorded with film/filter combination 2403/47B. Haze and air pollution drastically affect the contrast and detail in the aerial photography. Because of the limited number of clear days, the effect of adverse weather conditions other than haze on multiband imagery needs to be established. Knowledge of these effects on multiband imagery and possible compensating adjustments on camera settings could improve the effectiveness of an aerial surveillance system.

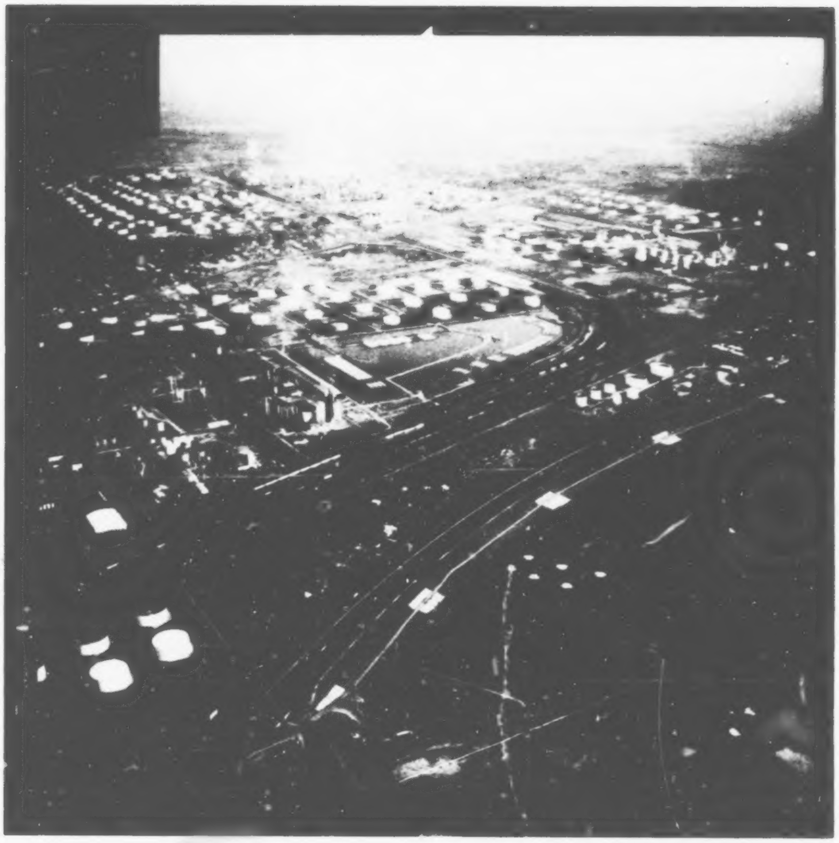
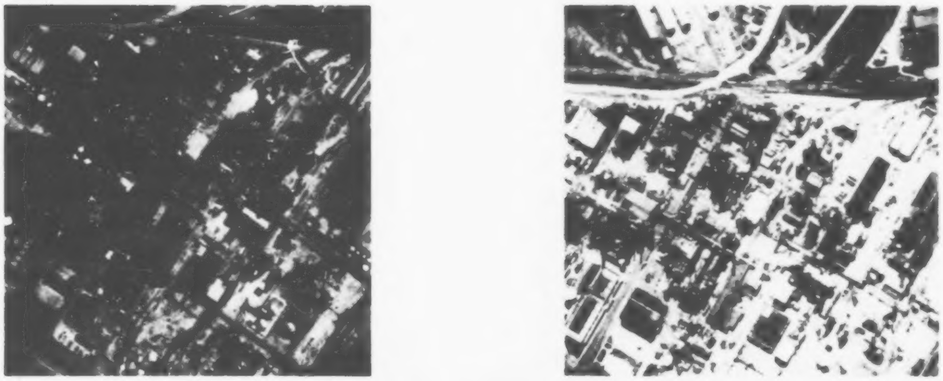


Figure 43 Oblique imagery of oil refinery

Effectiveness of Temporal Change Detection

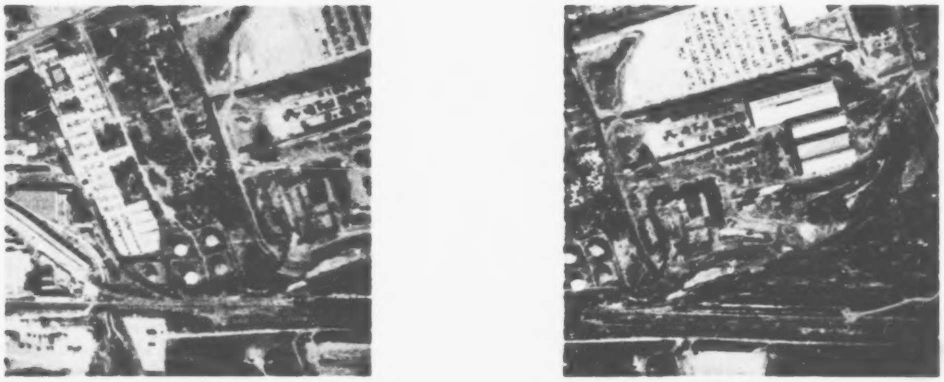
Detailed image analysis of the multiband imagery revealed the effectiveness of an aerial surveillance system as a temporal change detector. For the multiband analysis, the photointerpreter had to be careful to choose imagery containing the same or similar information even though the flights were made on different days. Imagery not containing the same information points out the effectiveness of an aerial surveillance systems as a temporal change detector. In Figs. 45a and 45b are aerial color images of steel-waste lagoons photographed on sequential days. As can be seen, the material in these lagoons has changed drastically from one day to the next, indicating a high flow rate. From the multiband imagery it was concluded that an aerial surveillance system can be an effective temporal detector for determining flow rates, spill clean-up time, stagnant lagoons, newly formed waste areas, and rate of usage of raw materials.



a

b

Figure 44 Imagery recorded on a (a) hazy and (b) clear day



a)

b)

Figure 45 Imagery of same area photographed on sequential days

# SECTION VII

## GENERAL SUMMARY OF IMAGE ANALYSIS

The value of multiband photography is in detecting and identifying spill threats and effluent materials through their spectral signatures. It is imperative to identify oil and hazardous material spills before a potential or real threat can be determined. Multiband photography is also helpful in determining flow and drainage patterns in waste areas and lagoons.

The best film/filter combinations for oil detection were found to be 2403/99, 2403/32, 2424/99, and 2424/32. The same filter was used with both film types 2403 and 2424 because each film offers advantages for particular backgrounds. Film type 2424 records the water near-infrared absorption and reduces the oil water contrast. Thus, film type 2403 is best for oil detection in large water areas such as oil-oxidation ponds. It is also more effective than film 2424 in oil detection in waste areas where water ponds and moist ground are intermingled with the oil waste. The detection of near-infrared reflected radiation from water and ground moisture by film 2424 results in imagery containing many shades of grey that can be mistaken for oil. Film type 2403 reduces the contrast of these water areas, thereby accentuating oil detection.

For a uniform ground background, however, the near-infrared reflected background radiation recorded on film type 2424 enhances oil detection. It should be emphasized that filter 99 is used to achieve a negative contrast enhancement by suppressing the oil-reflected radiation. Substituting filter 32 for 99 results in sensing the ultraviolet, blue, and red portion of the spectrum reflected by oil. While the corresponding image contrast is not as great as that obtained with filter 99, more detail of the oil distribution in water or on the ground is observed. Similar results were obtained by substituting filter 35 for filter 32. Filter 32, however, transmits more of the blue and red portion of the spectrum than filter 35. Likewise, filters 98 and 75 yielded imagery that was only slightly inferior to that obtained with filter 99. This is expected as filters 98 and 75 begin to transmit in the blue spectral region.

Other oil refinery materials investigated with multiband photography were spilled gasoline, lime sludge waste, and an oxidation pond effluent. The gasoline spill and lime sludge waste imagery were both enhanced through use of film/filter combinations 2403/65 and 2403/99. Color photography, however, was equally effective in detecting these materials. The imagery obtained with filters 18A, 47B, and 39 showed some water penetration as flow patterns were evident in the oil oxidation ponds. Although this filter does record the ultraviolet radiation reflected from oil, less oil water contrast is observed with this imagery than with the imagery recorded with the film/filter combinations described above. Similar imaging results for filters 18A, 47B, and 39 were observed at the oil refinery effluent. Color photography is as efficient in detecting the effluent as any of the multiband imagery.

In other industrial areas, only slight contrast enhancement of spills and effluents and raw materials was observed on the multiband imagery. Thus, color photography was concluded to be the best detector for these areas.

The baseline photographs of industrial areas were found to be effective in identifying potential and real threats to inland waterways from storage equipment, pipeline systems, tank farms, dike conditions, and the presence of trash and debris in diked areas. In many cases, the materials stored in various tanks could be determined from the tank geometry and construction. Protective measures such as tank diking were also determined from baseline photographs. While spill threats and effluents are evident on the black and white baseline imagery, color and multiband imagery are more effective in identifying the spill threats and effluent materials. Baseline stereographic pairs were also used to identify potential and real threats by estimating dike and tank heights, drainage patterns, and the runoff pattern of openly stored raw materials. While the areas of lagoons and ponds could be approximated from base photography, the lack of depth information prevented accurate determination of the lagoon and pond volumes. Accurate flow rates of ponds and lagoons could not be determined from the baseline imagery.

During the image analysis, various techniques were employed to extract the maximum amount of information from the imagery. These included adequate choice of image scale for baseline and multiband flights, stereographic image analysis, comparative coverage analysis, and ground truth correlation.

The baseline flights were flown at altitudes ranging from 1300 to 3000 ft above the ground. For the 6 in. focal length Zeiss lens, the image scale ranged from 1:2600 to 1:6000, respectively. From this imagery, the necessary mensuration work was easily performed. The scale also allowed identifying individual pipelines with the aid of 10X magnifier. For the 9 in. base film format, ground coverage of 3000 ft was sufficient to identify a large area of the largest industrial site of interest. This simplified the construction of mosaics of the total industrial area. The use of a smaller image scale would have increased the number of individual frames and increased the complexity of mosaic construction.

Multiband imagery obtained from an altitude of 1500 ft above the ground with the 50 mm Hasselblad lens had a scale factor of 1:9000. This scale was found to be adequate for image detection of spill threats, effluents, waste lagoons, raw material storage, and waste areas. These areas were easily identifiable in oil industry imagery while a 10X magnifier was helpful in examining other industrial imagery.

Stereoscopic analysis of baseline images is necessary for determining tank and dike heights, drainage patterns, and the volume of openly stored raw materials. Stereoscopic analysis was found to help in material identification. Knowledge of the height of a waste area relative to the surrounding area can aid in determining the type of material in a particular area. A depresseion can be representative of a quarry while a rise can be evidence of dumped waste.

Comparative coverage was found to be useful in positively determining the best film/filter combination for material identification. This technique compared the film/filter sections for material identification in one area with those in another area. The use of this technique in Section VI is obvious. Many more comparisons were employed than those included in this report. It is also advantageous to compare dissimilar areas. For example, in a bulk oil storage area, the film/filter effectiveness was determined by comparing oil and water spills.

Perhaps the single most valuable technique for determining the system effectiveness was the correlation of ground truth information with baseline and multiband imagery. As pointed out earlier, multiband flight lines were selected where ground truth information and imagery were available.

The use of the techniques discussed above has resulted in a surveillance system that has maximum effectiveness for detecting real and potential spill threats.

# SECTION VIII

# EQUIPMENT, PERSONNEL AND PROCEDURES FOR SYSTEM IMPLEMENTATION

The equipment, personnel, and procedures necessary to implement an aerial surveillance system such as that employed during this project are discussed in this section.

The equipment necessary for an aerial surveillance system can be subdivided into three categories: flight equipment, film processing equipment, and image analysis equipment. The flight equipment includes the Zeiss mapping camera or equivalent, for baseline imagery and four Hasselblad cameras or equivalent, for the multiband imagery. The latter require additional accessories, such as filters, filter holders, batteries, battery chargers,a command unit to trigger the four cameras simultaneously, quick mounts, and at least 16 cassettes. Additional magazines are not a necessity but do allow inflight camera reloading. The specific Hasselblad lenses depend on the required scale and flight altitude.

The film processing equipment for both 70-mm black-and-white and color film includes 70-mm Nikor reel and tanks capable of handling 15 ft. of film, a Pierce "ROK-IT" agitator to provide chemical agitation during processing, and an Oscar Fisher dryer. In addition, the chemicals, such as developer, fix and hypo-clearing bath, are needed for processing the black-and-white film. Kodak E-3 chemical kits provide the color processing chemistry. The use of these chemicals is described in Appendix B. The 9-in. black-and-white and color film can be hand processed but with considerable difficulty. A Versamat processing system would allow the processing of both 9-in. and 70-mm color and black-and-white photography. The Versamat, however, represents a large initial investment, but greatly facilitates film processing. For a long-term program, such a system would pay for itself. Without Versamat development, additional general processing facilities are required, such as temperature controlled water baths, thermometers, trays, and associated glassware. It is also necessary to provide 70-mm and 9-in. reels and cans. If the processing is to be performed commercially, only those companies capable of performing precision processing should be considered.

A standard light table with 10X and 30X magnifiers and a stereoscope are absolutely necessary for image analysis. An Air Force Height Finder (parallax bar) is needed to determine drainage patterns and estimate the heights of tanks, dikes, and waste piles. To do actual contouring of land areas, a paper print stereo-plotter is required.

Three or four personnel are required to implement an aerial surveillance system independent of the pilot and any supervisory personnel. These consist of one to two film processors, an aerial cameraman, and a photointerpreter.

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The number of film processors will depend on the amount of film to be processed and on the required turn around time. (During this project, one person processed 70-mm black-and-white film, while another processed the 70-mm color film. Versamat development was used only on the 9-in. film. Two people were necessary because of the time factor involved and the large quantity of exposed film.) These individuals need a strong background in dark room and processing techniques.

An experienced aerial photographer is also required for obtaining the aerial imagery. This individual needs to be well-versed on aerial camera systems, and to be able to determine the camera exposure, the intervalometer setting to achieve the degree of overlap, load and unload the cameras, and coordinate with the photointerpreter in determining the flight plan.

One of the functions of the photointerpreter is to determine the flight plan with the aerial photographer. The flight plan includes the proper aircraft headings, the number of exposures, and the number of flight lines and altitude needed to adequately cover the target area. In addition, the photointerpreter is also required to perform the image analysis. At minimum, the photointerpreter should have the equivalent knowledge of a military photointerpreter. This background enables him to identify industrial storage, processing, and transfer areas, to perform the stereoscopic and mensuration analysis, and to correlate the images with existing maps. At maximum, the photointerpreter should be able to apply his analysis to the location and identification of potential and real spill threats to inland waterways. This further includes the identification of oil and hazardous materials on multiband imagery and requires him to understand the use of spectral filters in conjunction with film spectral sensitivity and the general laws of reflection and absorption.

The procedures for attaining aerial imagery can be divided into two tasks. The first task consists of obtaining a general survey of an industrial area or areas for assessment of potential and real spill threats to the inland waterways. Having chosen a specific industrial site or sites, a baseline flight is flown with 9-in. black-and-white film. Upon processing, the photointerpreter notes particular areas on the baseline photography over which multiband imagery is required to positively identify an unknown spill to determine whether it is a threat to the inland waterway. Three film/filter combinations are chosen for three of the Hasselblad cameras while the fourth camera contains color film type 2448. The flight plan, including the area of interest, number of exposures required to cover this area, flight lines, altitude, camera settings and aircraft headings would be determined before the flight. Upon completion of the flight, the film is processed and given to the photointerpreter. He uses the multiband imagery to identify the materials and drainage patterns of the particular spill threats, waste areas and effluents originally noted on the baseline photography.

The second task involves the collection of imagery of a specific predetermined area. In this case, both the baseline and multiband camera array are flown simultaneously. Under these conditions the baseline camera would contain 9-in. color film while four film/filter combinations would be contained in the Hasselblad array. The baseline photography is still used for mensuration work but also provides the color imagery to be used in conjunction with the multiband images. The procedure for obtaining this imagery is essentially the same as above. The Hasselblad magazines are limited to 70 exposures while the Zeiss camera can achieve in excess of 110 exposures. Thus, the photographer would have to choose in flight the multiband targets of interest. Hence the Hasselblad cameras would have to be triggered manually while the Zeiss camera would be automatically triggered by the intervelometer. Both film types would be processed and given to the photointerpreter for image analysis.

By excluding processing time and photographer manhours, the cost of a single multiband flight can be approximated. First, assume that both the Zeiss and four Hasselblad cameras are flown simultaneously. A 125 ft roll of 9-in. color film type 2448 costs approximately $100. A 150 ft roll of 70-mm film type 2403 and 2484 costs approximately $12 and $18, respectively. Two cameras will be loaded with each type of film for optimum multiband imagery. Since each camera holds 15 ft lengths, the film expense per flight calculates to only $6.00. Under this contract, one hour of flight time, required to exhaust the camera magazines, costs approximately $115. Thus, a typical multiband flight would cost approximately $221.

If the base and multiband flights are flown sequentially, the total cost is found to be slightly higher. Black-and-white 9-in. film for the Zeiss camera costs approximately $43. The multiband film for three cameras containing film types 2403 and 2424 would cost $4.20. The 70-mm color film costs approximately $18 for a 15 ft length. Since two flight costs are required, the flight cost increases to $230. Therefore, the total cost of the sequential flight would be $295.20. The above calculations are independent of the initial camera costs. The four Hasselblad cameras and accessories cost approximately $4500. The cost of the Zeiss camera, including view finder, mounts, and other accessories, is estimated at $28,000.

## SECTION IX

## ACKNOWLEDGEMENTS

The work herein reported was performed by personnel of the Reconnaissance Laboratory at McDonnell Aircraft Company. Mr. Charles L. Rudder was the Principal Investigator on the Program. Mr. Charles J. Reinheimer assisted in guiding the flight test effort and performed data correlation and evaluation. Mr. Joseph L. Berrey participated in the flight program, ground truth collection and image evaluation and mensuration. Messrs. Raymond M. Bradley, William A. Dalton, Erich D. Kassler, John T. Smith, and Robert E. Thompson each made invaluable contributions.

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# APPENDIX A

## FILM AND FILTER SPECTRAL CHARACTERISTICS

The identification of target materials from their reflective characteristics can be achieved in aerial photography. The technique, called multiband photography, requires recording spectral characteristics of targets in multiple but separate images. Data recorded in the imagery are determined by the combined film and filter spectral response. Approximate target material identification is accomplished by interpreting the contrast, or lack of contrast, between the target and its surround in the imagery. Oil products are known to reflect strongly in the ultraviolet, blue, and red portions of the spectrum. Thus by selecting the film and filter combinations that record only these portions of the spectrum, one can enhance the contrast of oil products in the photographic image. This technique is called positive contrast enhancement. By choosing a filter that absorbs the reflected target radiation, image contrast enhancement can also be achieved. This process is known as negative contrast enhancement. Filters have been chosen for multiband photographic evaluation that both transmit and absorb radiation reflected from oil products. Additional filters were chosen that transmitted adjacent and overlapping spectral bands in the visible portion of the spectrum.

The spectral characteristics of Kodak Tri-X Aerographic film type 2403, Kodak Infrared Aerographic film type 2424, and Kodak Recording film type 2475 are shown in Fig. 1. Only the film type number rather than the descriptive title are specified in this report. Also, film and filter combinations are specified as film/filter. Hence, the use of film type 2403 and filter 32 is denoted 2403/32. Film type 2475 is an instrument recording film that was added to the program because of its increased ultraviolet sensitivity. These films were used with various filters for the multiband photography. The spectral characteristics of Kodak Ektachrome MS Aerographic film type 2448 and Kodak Aerochrome film type 2443 are shown in Fig. 2. Film type 2448 is normal color film while film type 2443 is called false color film. These films contain three different emulsions that are combined to provide the color imagery. For the altitudes flown, film type 2448 was used with Kodak HF3 haze filter while film type 2443 was used with a Kodak 12 filter. As recommended by the manufacturer, a CC10M filter was also used with this particular batch of film type 2443 to achieve the proper color balance. These filter transmission curves are shown in Fig. 3a, 3b, and 3c, respectively. The Kodak filters chosen for the multiband work were filters 18A, 47B, 39, 32, 35, 65, 75, 98, 99, and 25. The transmissions of these filters are shown in Figs. 4, 5, 6 and 7. Filter 25 is the standard filter used with film type 2424. Filters 18A, 47B, and 39 were chosen for their ultraviolet and blue transmittance where oil is known to reflect strongly. These filters, when combined with film types 2403 and 2475, would restrict the imaged radiation to these spectral bands. This can be seen by comparing Fig. 1 and Fig. 4. When these filters were combined with film type 2424, the near-infrared portion of the spectrum (700 to 850 nm) reflected from the target was also included.

Filters 99, 98, and 75 were chosen because of their absorption of blue and ultraviolet radiation. Thus, the use of these filters with film type 2403 and 2475 should yield images of oil products with negative contrast enhancement. When these filters were combined with film type 2424, only the near-infrared and yellow-green portions of the spectrum reflected from the target would be imaged. Oil has very little yellow-green reflectance properties. A comparison of the imagery on film types 2403 and 2424 allowed us to determine the relative reflective properties of oil in the near-infrared spectrum. Through the proper film and filter combination, the spectral characteristics of the target can be determined.

Some oil products are known to reflect red as well as ultraviolet and blue radiation. Filters 32 and 35 were included to evaluate the addition of the red spectral region for the detection of oil products.

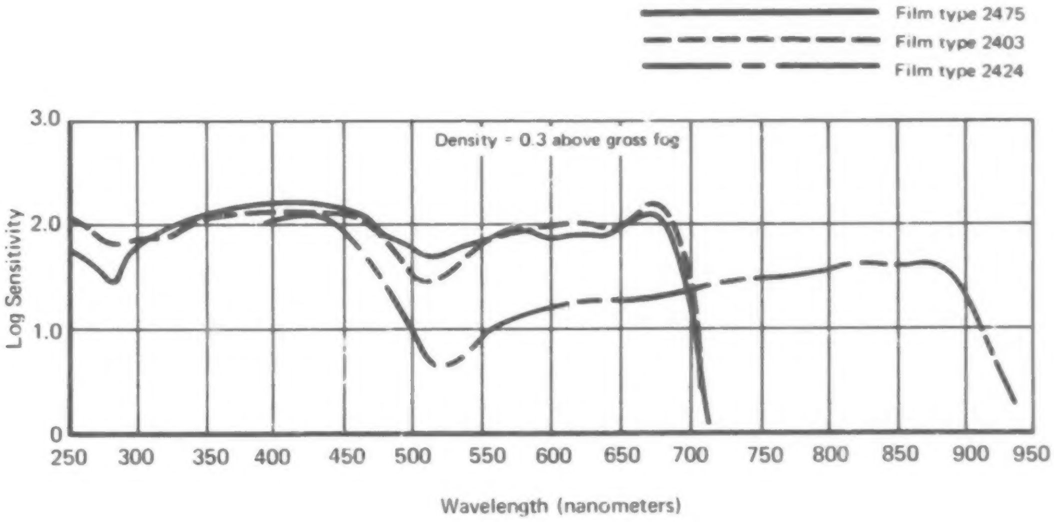

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Figure 1 Film spectral sensitivity

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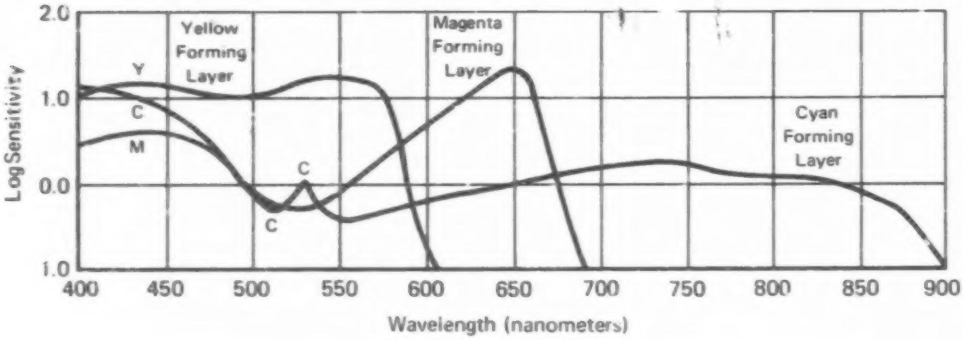
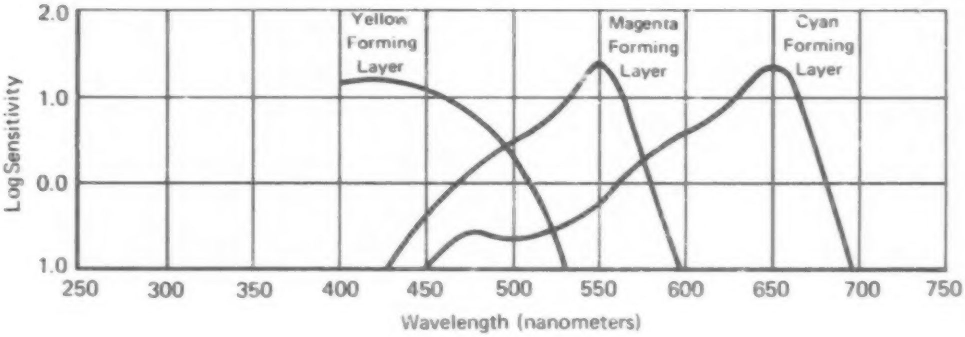


a) Film type 2443



b) Film type 2448

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Figure 2 Film spectral sensitivity

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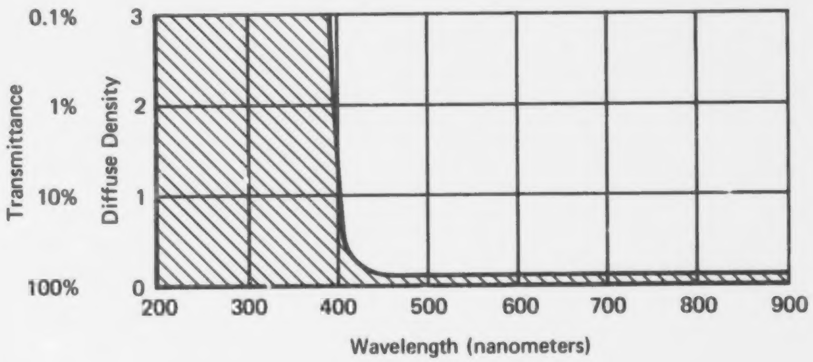
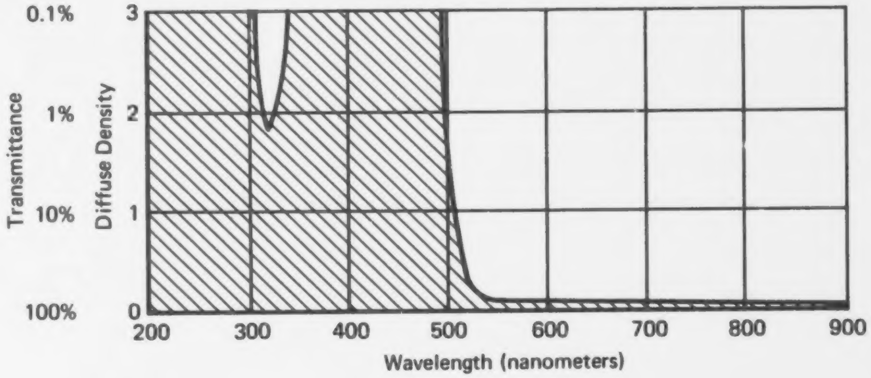
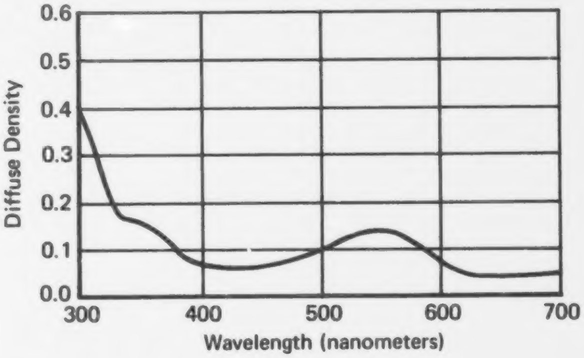


a) HF3



b) 12



c) CC10M

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Figure 3 Filter transmission

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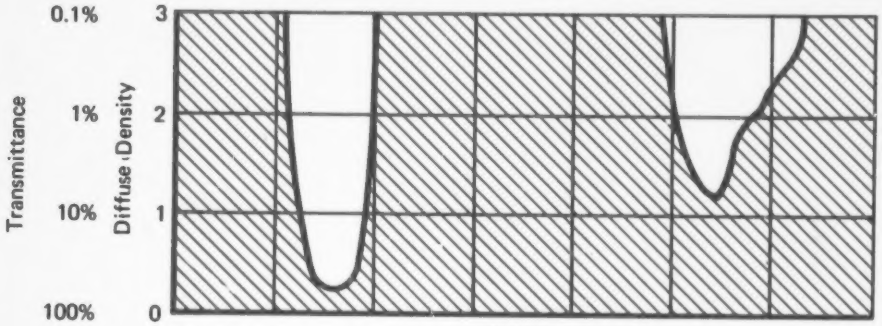
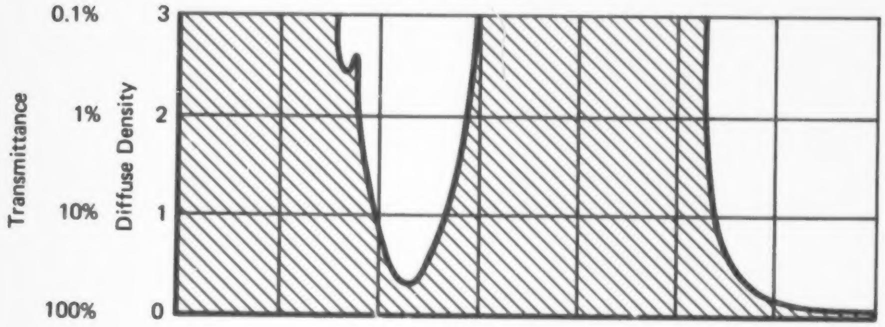
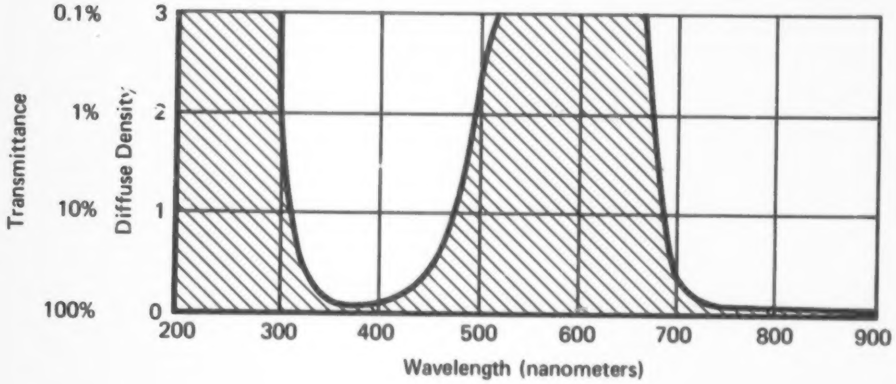


a) 18A



b) 47B



c) 39

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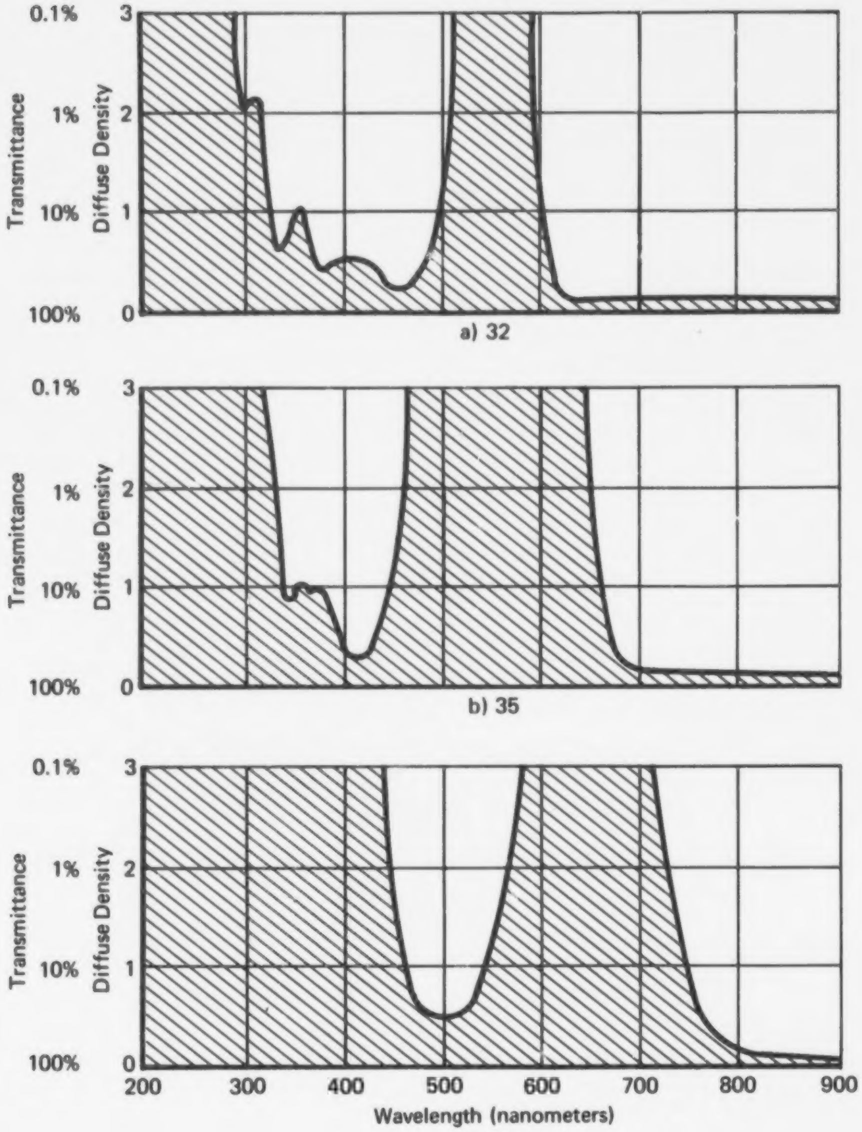
Figure 4 Filter transmission

GP71-1642-4



a) 32

b) 35

c) 65

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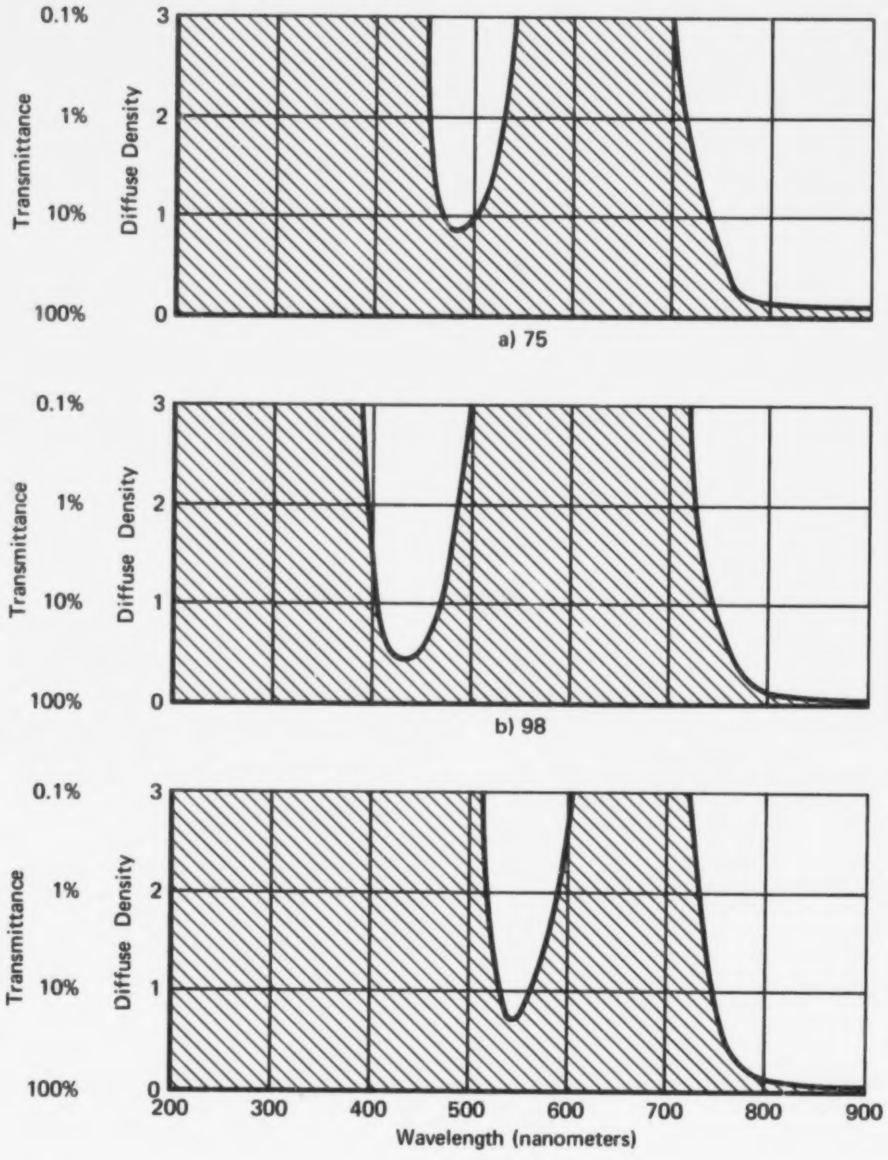
Figure 5 Filter transmission

GP71-1642-63



a) 75

b) 98

c) 99

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Figure 6 Filter transmission

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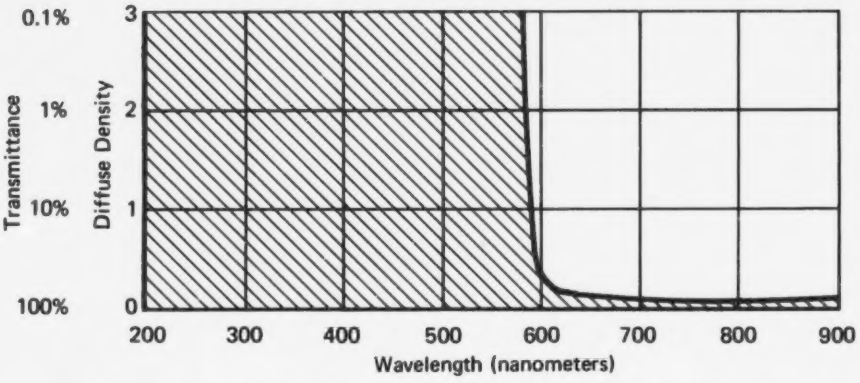

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Figure 7 Filter 25 Transmission

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# APPENDIX B

## PHOTOGRAPHIC PROCESSING

Precision photographic processing of the 70-mm film is necessary for the extraction of scientific data from multiband photographic images. Precision processing insures the tonal variation in the multiband images is a result of the target's reflectivity and not the result of inconsistencies in the processing techniques. The processing equipment should be lightweight and portable, capable of processing both black-and-white and color films, have minimal operating procedures, and cost less than a fully automatic processing system. This led to the selection of a Nikor 70-mm Reel and Tank Processor. The reels had a 15 ft capacity and the tanks had a 1/2 gal. capacity. The Nikor Film Loading Device was also selected. Film drying was accomplished with an Oscar Fisher forced hot air cabinet dryer. Agitation for black-and-white film processing was mechanically applied by a Pierce "ROK-IT" Agitator.

The color processing chemistries considered were Ektachrome Process E-3 and E-4. Both of these produce nearly the same results when used to process color films types 2448 and 2443. Since Process E-4 has two more solutions than Process E-3, E-3 processing was selected. The E-3 processing steps for color films types 2443 and 2448 are shown in Table 1.

The selection of the chemistry for processing of the three black-and-white film types 2403, 2424, and 2475 was more complicated. The design goal here was a single chemistry, common to the three films, which would produce the desired contrast range and film speed. Sensitometric experiments were conducted and analysis of the derived data indicated that development in D-19 would satisfy the requirements. The D-19 chemistry and functions relating to the processing of black-and-white films type 2403, 2424, and 2475 are contained in Table 2.

### Film Storage and Handling

It is a well recognized fact that unprocessed photographic film is perishable. Its sensitometric properties will deteriorate slowly with time. The deterioration is accelerated by high relative humidities and high temperatures. Sensitometric degradation is usually reflected in a speed loss, an increase in the base fog level, a contrast change, or any combination thereof. Color films can also exhibit changes in color balance. These known sensitometric changes in photographic films will not be encountered if film is stored and handled under proper conditions for reasonable periods of time. Films used for the airborne data collection phase of this contract were given strict environmental protection, from shipment through the processing. Films were packed in dry ice and shipped via air by the manufacturer. Upon receipt, the film was immediately stored in a deep freeze (long term) or in a refrigerator (short term). The film, after removal from refrigeration, was

Table 1 Chemistry for processing color film types 2443 and 2448

| Step | Function | Kodak Ektachrome process E-3 | Time (min) | Temperature (°F) |
|---|---|---|---|---|
| 1 | Develop | First developer | 10 | 75 ± 1/2 |
| 2 | Rinse | Water (4 gpm) | 1 | 75 ± 2 |
| 3 | Harden | Hardener | 3 | 75 ± 1/2 |
| 4 | Wash | Water (4 gpm) | 3 | 75 ± 2 |
| 5 | Re-expose | No. 2 photoflood | 1/2 | 75 ± 2 |
| 6 | Develop | Color developer | 15 | 75 ± 1/2 |
| 7 | Wash | Water (4 gpm) | 5 | 75 ± 2 |
| 8 | Clear | Clearing bath | 5 | 75 ± 1/2 |
| 9 | Bleach | Bleach | 8 | 75 ± 1/2 |
| 10 | Rinse | Water (4 gpm) | 1 | 75 ± 2 |
| 11 | Fix | Fixer | 6 | 75 ± 1/2 |
| 12 | Wash | Water (4 gpm) | 8 | 75 ± 2 |
| 13 | Stabilize | Stabilizer | 1 | 75 ± 2 |
| 14 | Dry | Forced hot air | 20 | 110 ± 8 |

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tempered at ambient room temperature (73°F) for not less than eight hours prior to the actual camera loading. Upon completion of magazine loadings, all unused film was resealed in metal cans and stored at ambient room temperature. All film handling (except that which occurred during the airborne flights) was conducted under ambient room temperatures of 73°F, or 75°F in the case of film processing. Actual environmental conditions relative to storage and handling of the films are shown in Table 3. Analysis of sensitometric data showed that neither a loss of film speed, an increase in fog level, or a change in color balance had occurred in any of the processed films. These results are attributed to the careful handling and storage of the unprocessed film as well as to precision processing techniques. Because of the interdependence of the various parameters, such as temperature humidity and the time the film is maintained at unfavorable conditions, it is difficult to estimate the amount of film degradation if these procedures are not followed.

Table 2 Chemistry for processing of film types 2403, 2424 and 2475

| Step | Function | Agent | Time (min) | Temperature ($^0$F) |
|---|---|---|---|---|
| 1 | Develop | Kodak D-19 | 8 | 75 ± 1/2 |
| 2 | Stop | Kodak Indicator Stop | 1 | 75 ± 1/2 |
| 3 | Fix | Kodak Rapid Fixer | 5 | 75 ± 1/2 |
| 4 | Rinse | Water (4 gpm) | 1 | 75 ± 2 |
| 5 | Clearing | Kodak Clearing Agent | 2 | 75 ± 1/2 |
| 6 | Wash | Water (4 gpm) | 5 | 75 ± 2 |
| 7 | Wetting agent | Kodak Photo-Flo 200 | 1 | 75 ± 2 |
| 8 | Dry | Forced hot air | 15 | 160 ± 10 |

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Table 3 Enviornmental conditions for film storage and handling

| Type of film storage and handling | Environmental conditions | | |
|---|---|---|---|
| | Type area | Temperature ($^0$F) | Relative humidity (%) |
| Long term | Deep freeze | $-4^{+-2}_{--4}$ | 70 ± 6 |
| Short term | Refrigeration | 40 ± 3 | 44 ± 6 |
| Tempering | Air conditioned | 73 ± 1 | 45 ± 5 |
| Loading | Air conditioned | 73 ± 1 | 45 ± 5 |
| Processing | Air conditioned | 75 ± 1 | 45 ± 5 |

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## Film Processing Procedure

For color processing the solution tanks were partially immersed in recirculating water temperature controlled at 75°F. Agitation was performed by the tip-and-tilt method as prescribed for Nikor Reel and Tank Processing. As described earlier, the chemistry used was Kodak Ektachrome Process E-3, 1/2 gal. size. To minimize the chances of chemical contamination, a replenishment system was not used. Instead, freshly mixed chemicals were used for each 15 ft of film processed. Sensitometric control step wedges were processed with each 15 ft roll, and the derived characteristic H&D curves exhibited good process control and good color balance. Typical characteristic H&D curves for color film types 2448 and 2443 are shown in Fig. 1 and 2, respectively.

Black-and-white film processing was also accomplished by using Nikor stainless steel 70-mm by 15 ft reels and 1/2 gal. tanks. Solution tanks (except the developer) were partially immersed in temperature-controlled (75°F), circulating water. The tank with the developer solution sat on a Pierce Company, "ROK-IT" Agitator. The "ROK-IT" is an electromechanical device that rocks the developer solution. Automatic, rather than manual, agitation was used to provide repeatable processing conditions.

Gamma ($\gamma$) aim points, with allowable upper and lower limits, were established for each type of film. The selected gamma aim points were those that would provide the desired emulsion speed and contrast range. Sensitometric data derived from step wedges processed with the aerial imagery showed that in all cases, processing control was within the established limits. (See Fig. 3.) Process control step wedges were also processed with each reel of film. Densities of the wedges were measured and their numerical values plotted against the log of exposure. Other sensitometric data and typical characteristic H&D curves relative to the processing of the three films, types 2403, 2424, and 2475, are shown in Figs. 4, 5, 6, respectively. From the resultant characteristic curves, other necessary data such as minimum and maximum density, gamma and emulsion speed were obtained. Averages of these data are shown in Table 4.

## Sensitometric Data

Step tablet-Kodak 007 ST403; Sensitometer illumination - tungsten; Exposure - tungsten; Exposure time - .2 sec; Meter candle seconds - 340; Sensitometer filtration - Kodak # 309, Wratten #96, neutral density - 1.4; Development method - reel & tank; Developer - Ektachrome E-3; First development time - 10 min; Solution temperature - 75°F; Agitation method - manual tip and tilt; Densitometer filtration - Wratten #92, 98, & 99; Red $\gamma$ - 2.9, green $\gamma$ - 1.79 & blue $\gamma$ - 1.64; Emulsion speed (AEI) - red 9, green 3 & blue 1; Note - emulsion speed is effective for indicated processing only.

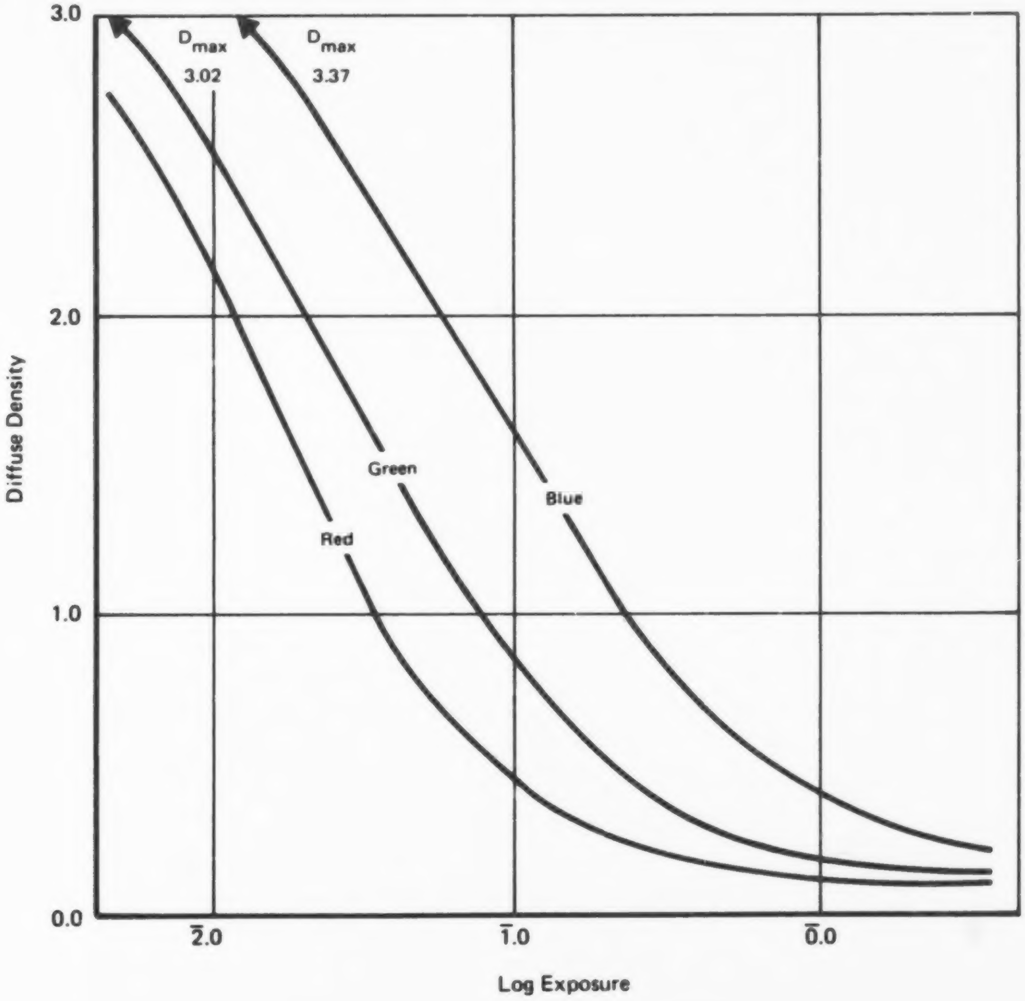

**Figure 1 Typical H&D curve for film type 2448**

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## Sensitometric Data

Step tablet-Kodak 007ST403; Sensitometer illumination - tungsten; Exposure time - .2 sec; Meter candle seconds - 340; Sensitometer filtration - Wratten #12 & 96, Kodak #301 & 309, neutral density - 1.4; Development method - reel & tank; Developer - Ektachrome E-3; First development time - 10 min; Solution temperature - 75°F; Agitation method - manual tip and tilt; Densitometer filtration - Wratten #92, 98 & 99; Infrared γ - 4.22, green γ - 3.07, blue γ - 5.45; Emulsion speed (AEI) - infrared 1.4, green - 12.5, blue - 17; Note - speed is effective for indicated processing only.

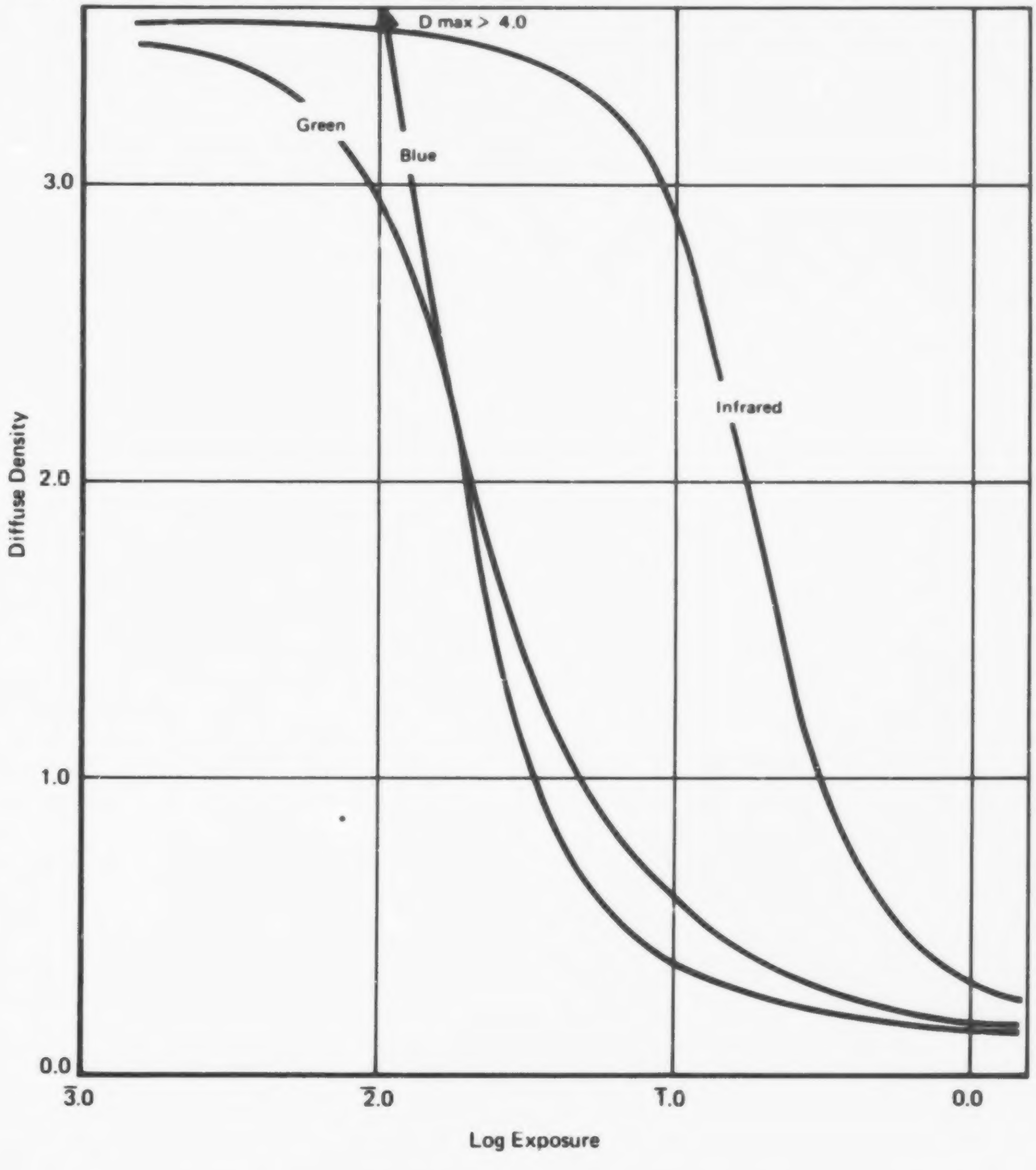

Figure 2 Typical H&D curve for film type 2443

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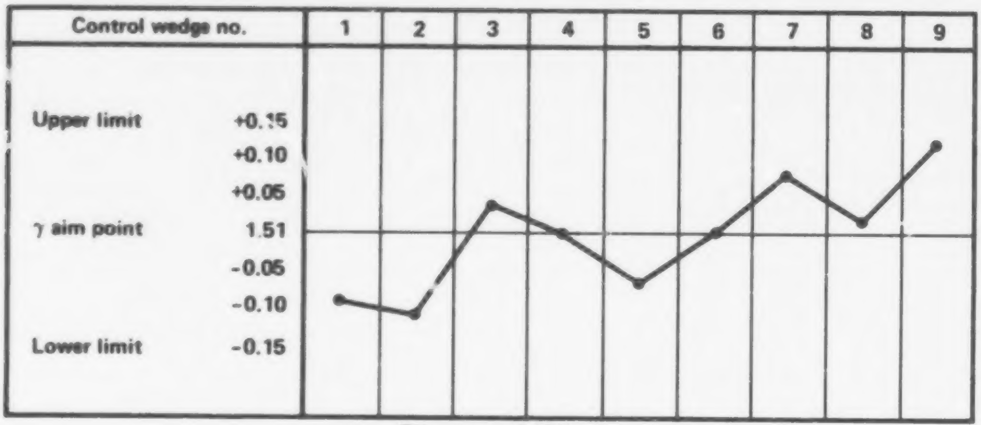
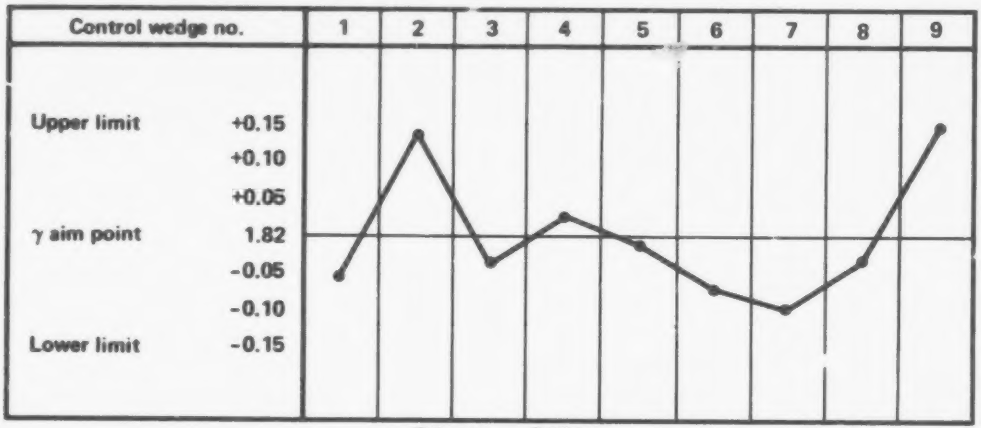
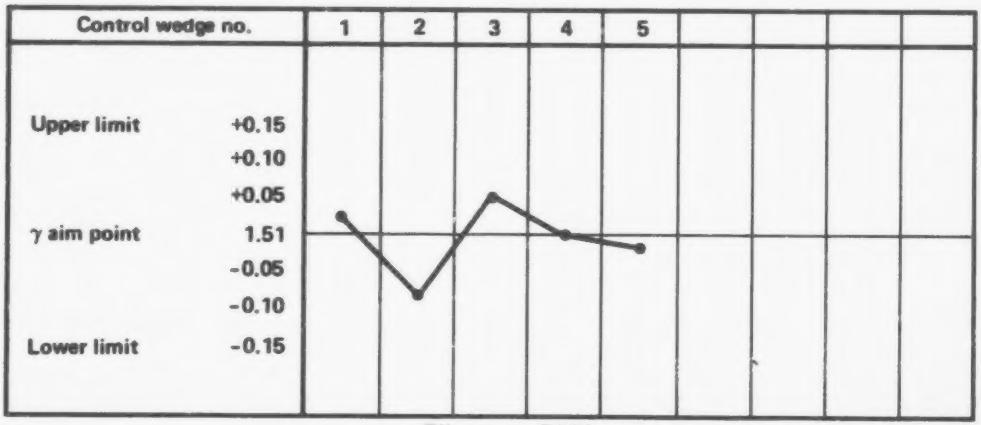


Film type 2403



Film type 2424



Film type 2475

**Figure 3** Gamma variation with film processing

GP71-1642-64

Sensitometric Data

Step tablet-Kodak 007ST403; Sensitometer illumination - tungsten; Exposure time - .2 sec; Meter candle seconds - 340; Sensitometer filtration - Wratten #96, neutral density - 3.1; Development method - reel & tank; Developer - D-19; Development time - 8 min; Solution temperature - 75°F; Agitation method - mechanical rocking; $\gamma$ - 1.51; Emulsion speed (AEI) - 284; Note - speed is effective for indicated processing only.

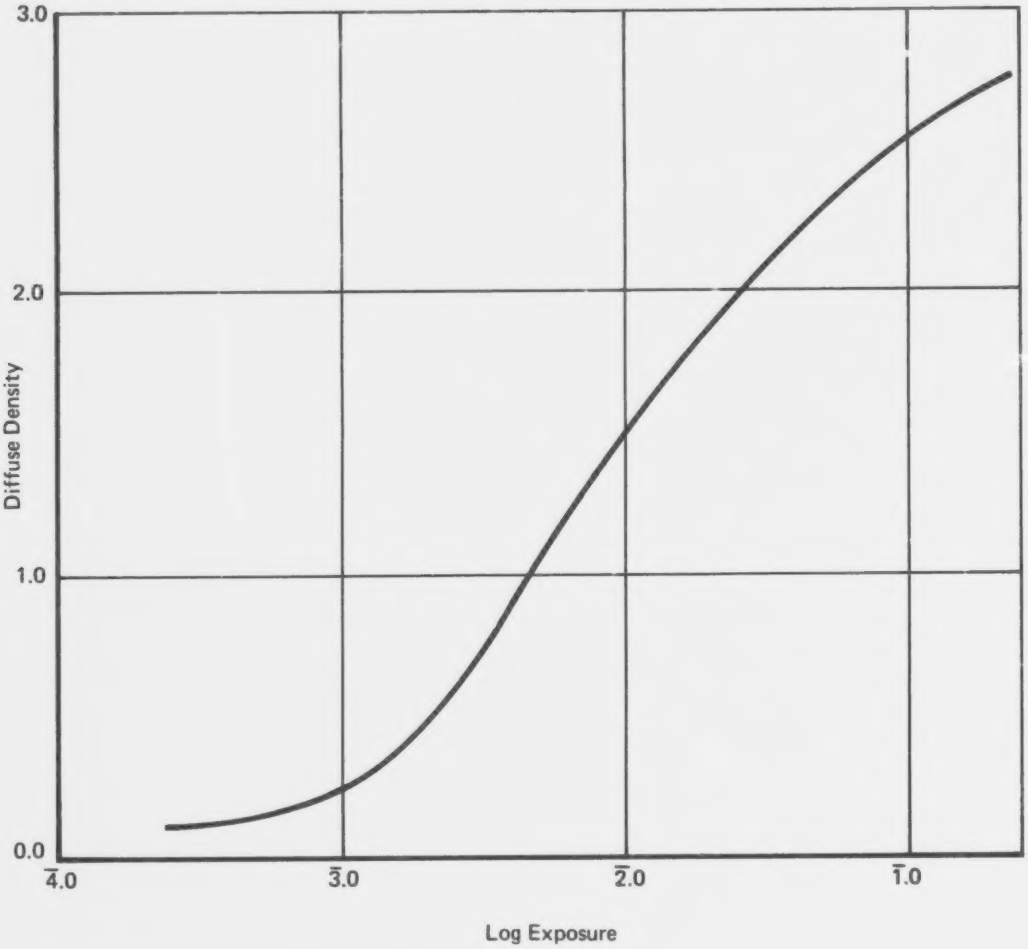


Figure 4 Typical H&D curve for film type 2403

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Sensitometric Data

Step tablet-Kodak 007ST403; Sensitometer illumination - tungsten; Exposure time - .2 sec; Meter candle seconds - 340; Sensitometer filtration - Wratten #96, neutral density - 2.78; Development method - reel and tank; Developer - D-19; Development time - 8 min; Solution temperature - 75$^{\circ}$F; Agitation method - mechanical rocking; $\gamma$ - 1.72; Emulsion speed (AEI) - 126; Note - emulsion speed is effective for indicated processing only.

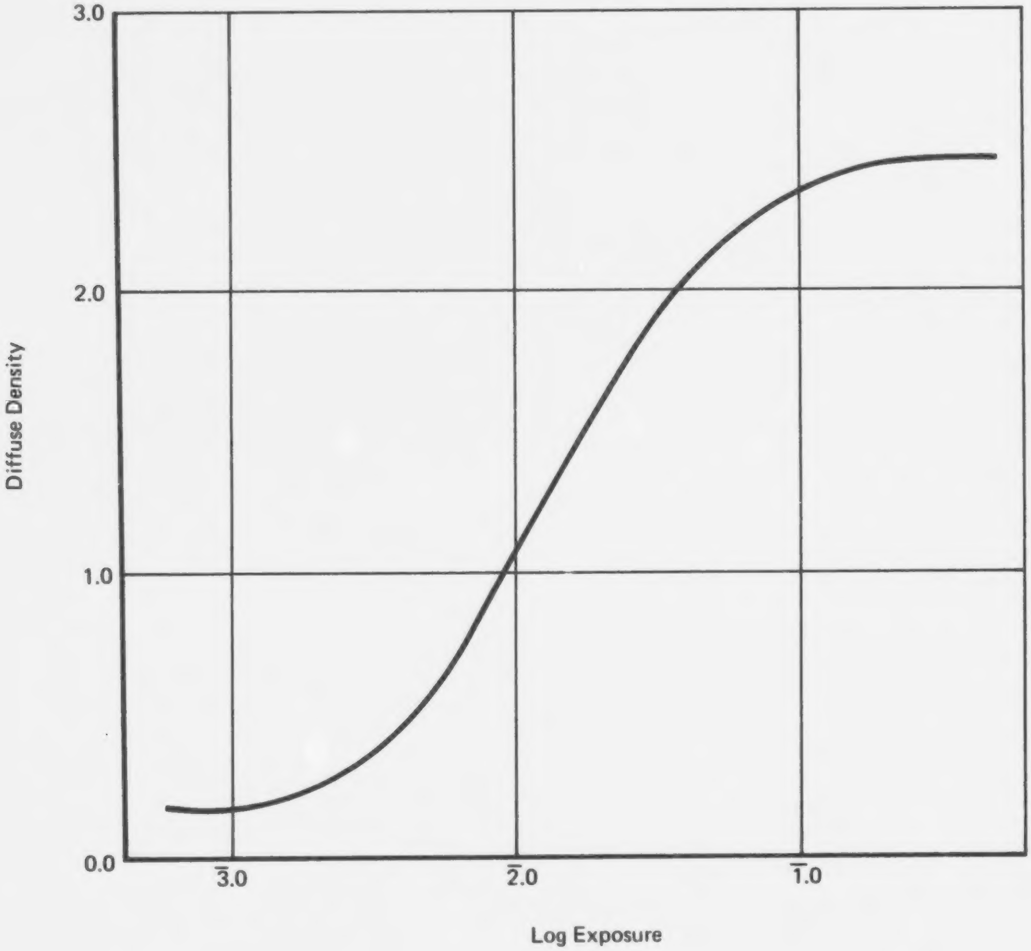

**Figure 5 Typical H&D curve for film type 2424**

GP71-1642-71

Sensitometric Data

Step tablet-Kodak 007ST403; Sensitometer illumination - tungsten; Exposure time - .2 sec; Meter candle seconds - 340; Sensitometer filtration - Wratten #96, neutral density - 3.2; Development method - reel & tank; Developer - D-19; Development time - 8 min; Solution temperature - 75°F; Agitation method - mechanical rocking; $\gamma$ - 1.51; Emulsion speed - AEI 330 & ASA 900; Note - emulsion speed is effective for indicated processing only.

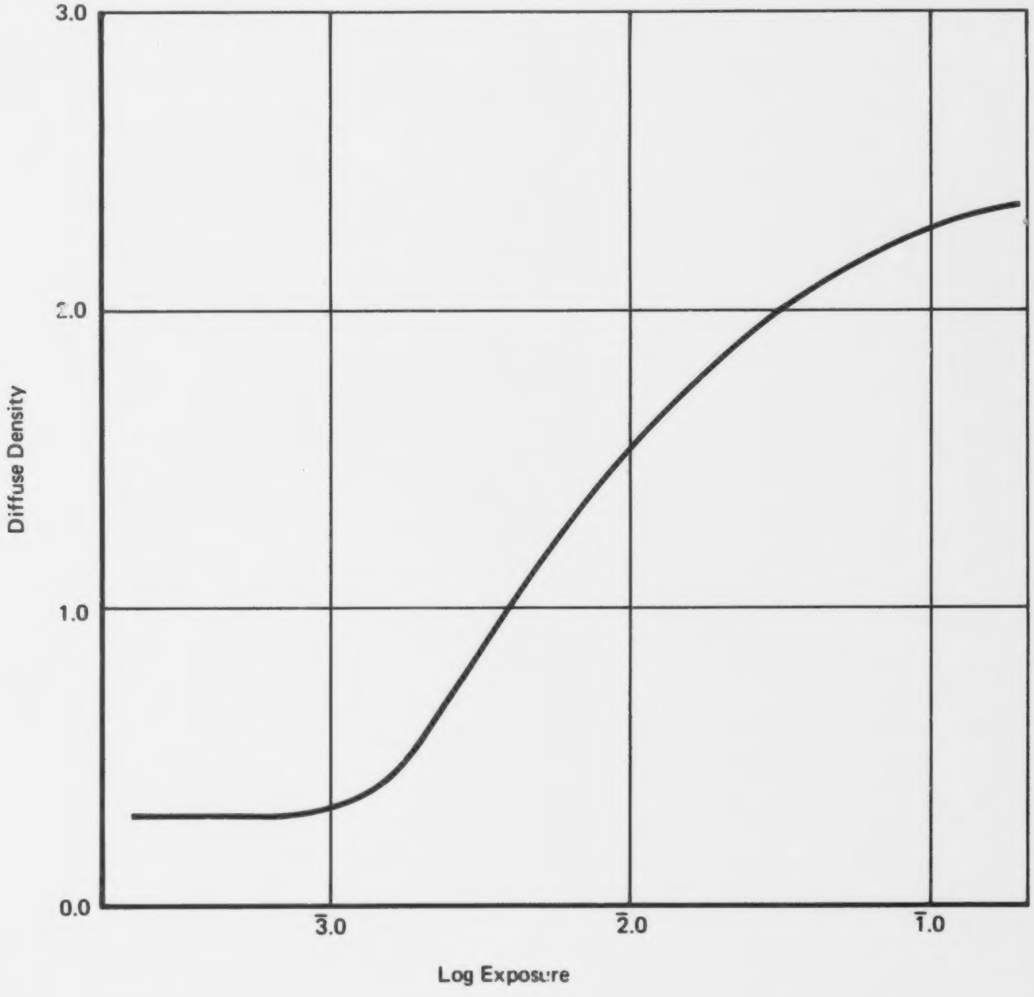

**Figure 6 Typical H&D curve for film type 2475**

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## Table 4 Sensitrometric data

| Film type | Emulsion | | Average | | | |
|---|---|---|---|---|---|---|
| | | | $D_{min}$ | $D_{max}$ | Gamma | Effective film speed |
| 2403 | Black and white (panchromatic) | | .09 | 2.71 | 1.51 | AEI 284 |
| 2424 | Black and white (panchromatic) | | .16 | 2.49 | 1.71 | AEI 126 |
| 2443 | Color (infrared) | Red | .27 | 3.57 | 4.25 | AEI 1.4 |
| | | Green | .12 | 3.44 | 3.03 | AEI 12.5 |
| | | Blue | .15 | $>$ 4.00 | 5.12 | AEI 17 |
| 2448 | Color (reversal) | Red | .07 | 2.66 | 2.12 | AEI 9 |
| | | Green | .12 | 2.80 | 1.82 | AEI 3 |
| | | Blue | .17 | 3.03 | 1.71 | AEI 1 |
| 2475 | Black and white (panchromatic) | | .32 | 2.41 | 1.51 | ASA 900 |

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# APPENDIX C

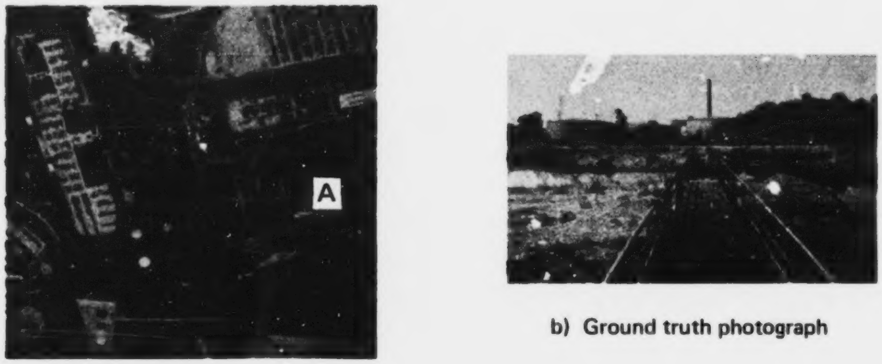
## STEEL MILL WASTE LAGOON MULTIBAND PHOTOGRAPHY

In the steel industry, waste storage lagoons contain a variety of materials. These materials include lubricating oil from the rolling mill cooling system, rust or iron which is acidicly removed from stored steel materials, and water from various cooling towers. The cooling water contains chemicals that are used to eliminate scale and fungus from the cooling towers. The lagoon that contains the above materials is treated with caustic soda to neutralize the acid and settle out solids (iron scale) and is then passed through a filtration pond before it is emptied into the river.

The steel mill waste lagoons shown in the color aerial photograph in Fig. 1a are spectrally characterized by a variety of colors. Before being treated with caustic soda, the lagoons are yellowish red in color. After treatment, the ponds acquired a rust-colored or a black appearance. The rust-colored area is iron or scale settlement. A ground truth team learned the black color is a residue resulting from the reaction of spent caustic soda with water. A photograph of a typical pond obtained during an initial ground truth mission is shown in Fig. 1b. Note the rust color appearance of the pond in the upper portion of the photograph while the pond to the right appears free of pollutants. The black and rust-colored appearance of the ponds settling area is contrasted with the untreated yellow portion of the lagoon labeled A.

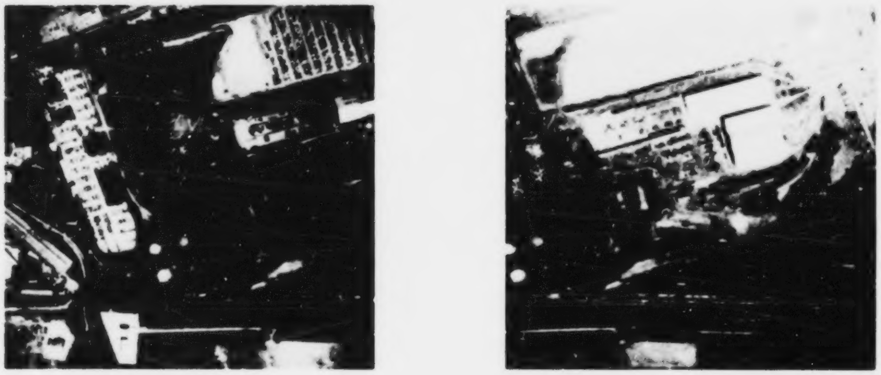
The value of multiband photography is in the identification of the materials present in these lagoons. These results can be applied to areas located adjacent to inland waterways to identify unknown spills and thus located potential and real spill sources threatening inland waterways. The multiband flights revealed that the film/filter combinations 2403/99, 2403/65, 2403/32, 2424/99, and 2424/35 gave the best image contrast for this area. These film/filter combinations are shown in Figs. 1c and 1d and 2a, 2b, and 2c, respectively. Only small differences were found in the imagery recorded with film type 2403 and filters 99, 98 and 75. The same conclusion was derived for these filters coupled with film type 2424. Similarly, there were only slight differences in the imagery recorded with filters 32 and 35. As can be seen from Figs. 1 and 2, the oil water area imagery is slightly darker for the 99 filter coupled with both film types 2403 and 2424. The imagery recorded with film/filter combination 2424/35 gives better area definition than the 2424/99 imagery. This is indicative of a spectral return in the ultraviolet and blue portions of the spectrum. The imagery recorded with film/filter combination 2403/32 and 2403/65 even better defines this area because of the water-reflected visible radiation. The film/filter combination 2424/35 imagery shows strong water absorption in the near-infrared. Thus it is difficult to distinguish oil from the water.

The yellowish lagoon has a light tone in the film/filter combination 2403/32 and 2403/65 imagery. On the imagery recorded with film/filter



b) Ground truth photograph

a) 2448/HF3



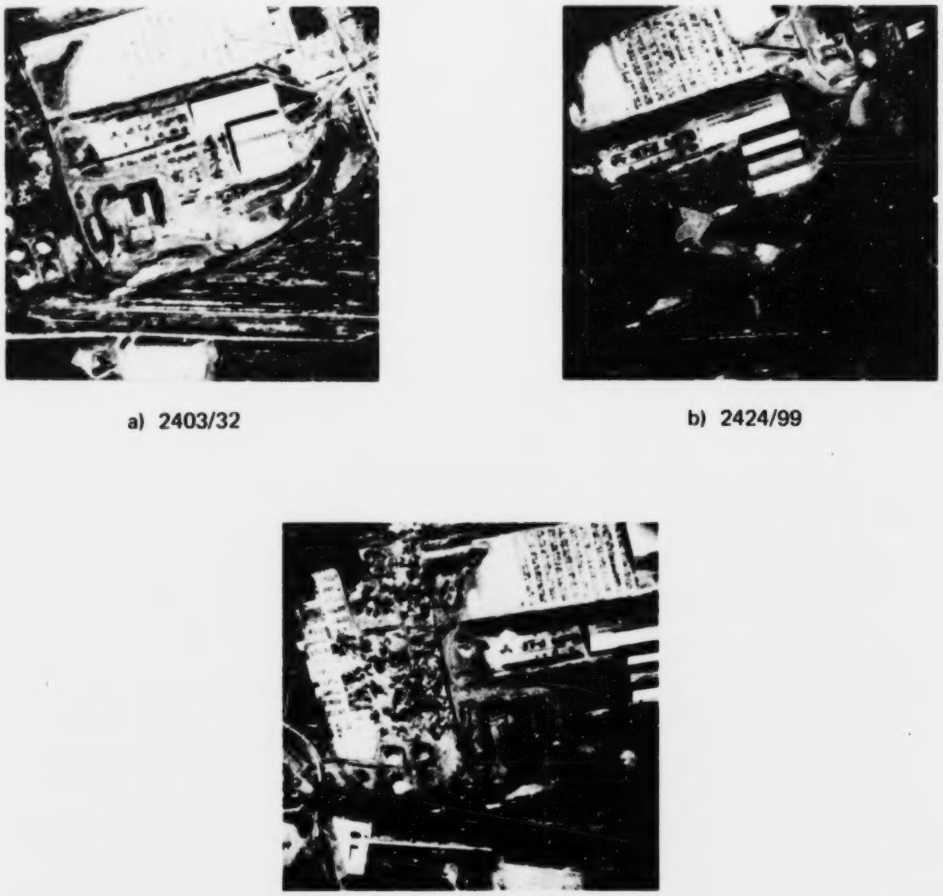
c) 2403/99

d) 2403/65

**Figure 1 Steel mill waste lagoon**

combinations 2403/99, 2424/99, and 2424/35, this area is dark in tonal quality, representing a complete contrast reversal. This area strongly reflects ultraviolet, blue, and green visible radiation and absorbs near-infrared radiation.

The rust-colored area shows small contrast variations in the imagery recorded on five film/filter combinations shown in Figs. 1 and 2. The imagery of this area obtained with film/filter combinations 2403/32 and 2424/35 is lighter than that obtained with filter 99 and film types 2403 and 2424. This is anticipated since filters 32 and 35 transmit the red portion of the spectrum. The imagery from film/filter combinations 2403/65 is darker in this area than that taken with film/filter combination 2403/32 because of blockage of the red spectral region. The imagery of this area taken with 2403/99 is lighter than that obtained



a) 2403/32

b) 2424/99

c) 2424/35

Figure 2 Steel mill waste lagoon

from 2403/65. This indicates some reflectance of this area in the 500 to 600 nm range. The imagery obtained with film types 2424/35 and 2424/99 is found to be darker than that obtained with 2403/32 and 2403/99, respectively. This indicates some near-infrared absorption by this area. A comparison of the imagery obtained with film/filter combinations 2424/35 and 2424/99 indicates that the red reflectance is greater than the near infrared absorption. Thus, the various film/filter combinations allow the spectral characteristics of the materials under investigation to be determined. One film/filter combination cannot be used effectively for detecting the three different areas defined in this lagoon. Color photography reveals the maximum amount of information.

# APPENDIX D

## OIL WASTE DUMP

Another oil waste area of 63 acres was covered during this project and is shown in Fig. 1. It is located 7,000 ft from the river and does not represent a direct threat to the inland waterway. In addition, the area is located on a flood plain and no distinct drainage pattern is observed. The area is of interest for two reasons, First, it represents a waste area that differs distinctly from other oil waste areas already discussed. The oil waste in this area is located in small patches dispersed among small, stagnant water ponds, vegetation, filter cakes and emulsified oil waste, which accounts for the mottled appearance of the image shown in Fig. 1. Second, the results of the multiband image analysis can in similar areas located adjacent to inland waterways to identify unknown spills. Upon identification, the potential or real threat of the spill source to the inland waterway can be evaluated.

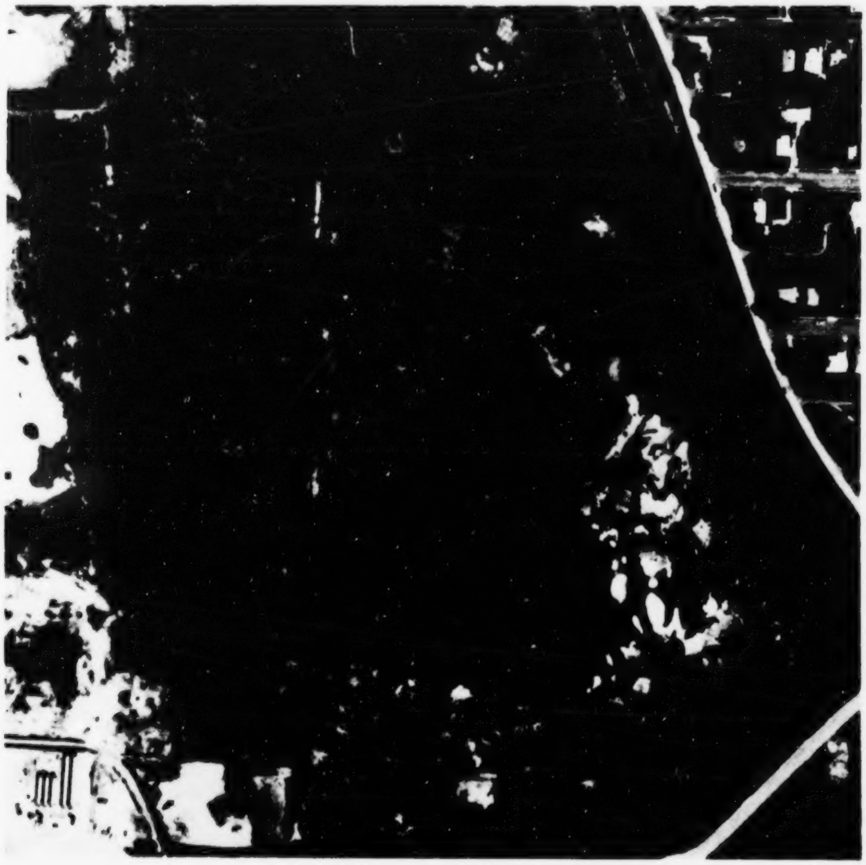
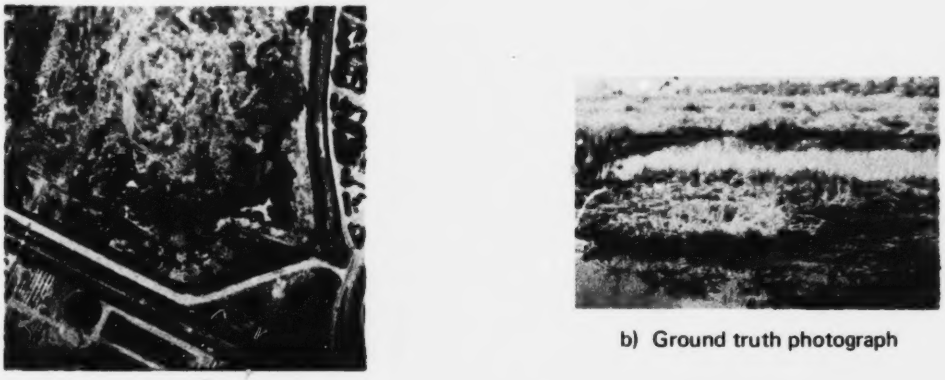


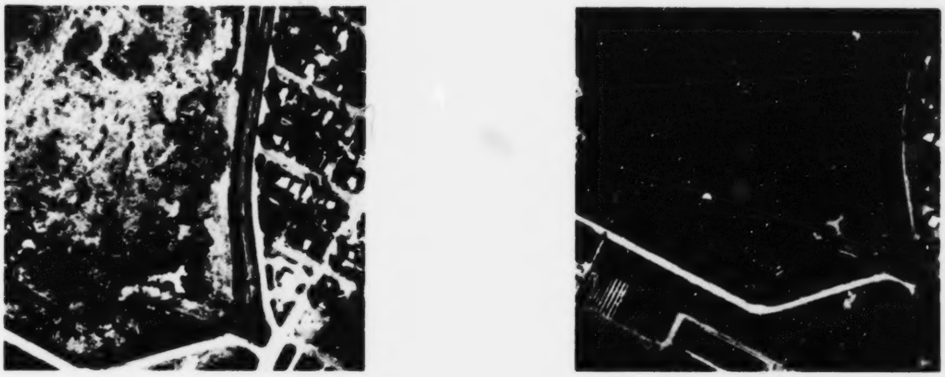
**Figure 1 Baseline imagery of oil refinery waste dump**

An aerial color photograph of the area obtained on the multiband flights is shown in Fig. 2a. An accompanying ground truth photograph of the oil lying on the ground is shown in Fig. 2b. The multiband imagery revealed the best film/filter combinations for contrast enhancement were 2403/32, 2403/99, 2424/32, and 2424/99. Images of the area using these film/filter combinations are shown in Figs. 2c, 2d, 2e and 2f, respectively. As concluded in the preceding section, color photography appears best in identifying the emulsified oil waste and filter cakes. The emphasis here is on separating the black oil waste from the background material. The imagery recorded with filter 99 for both film types 2424 and 2403 gives the maximum negative enhancement of the oil to the background when compared with the imagery recorded with filter 32. Filter 99's absorption of the ultraviolet, blue, and red radiation reflected by oil is responsible for this. When comparing film type 2424 and 2403 imagery, better oil background contrast with type 2424 is observed because of the near-infrared reflectance of the background. Because of the water near-infrared absorption, however, it is sometimes difficult to distinguish oil from water on film type 2424 imagery. Furthermore, the moisture content of various ground regions produces a variety of shades of gray on film type 2424, tending to distract the photointerpreter. On film type 2403 imagery, these shades of gray are subdued as the water ponds do not absorb as much visible radiation making it easier to detect oil from water. For these reasons, film/filter combinations 2403/99 and 2403/32 would be more effective than 2424/99 and 2424/32 in detecting oil waste in this particular type of area.



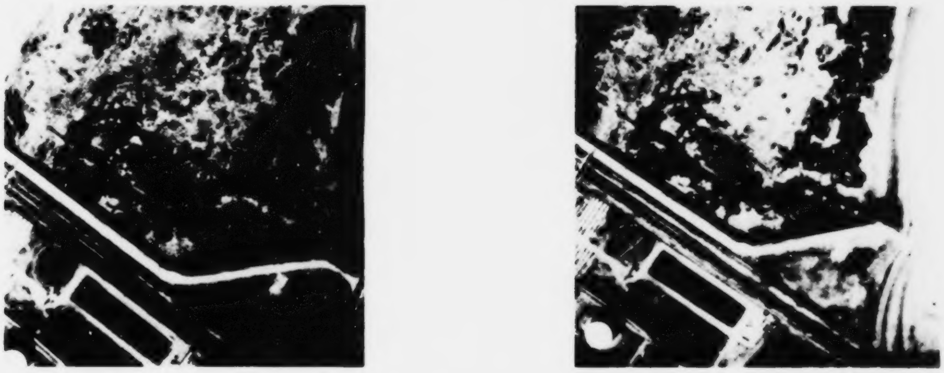
a) 2448/HF3

b) Ground truth photograph



c) 2403/32

d) 2403/99



e) 2424/32

f) 2424/99

Figure 2 Oil waste dump

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